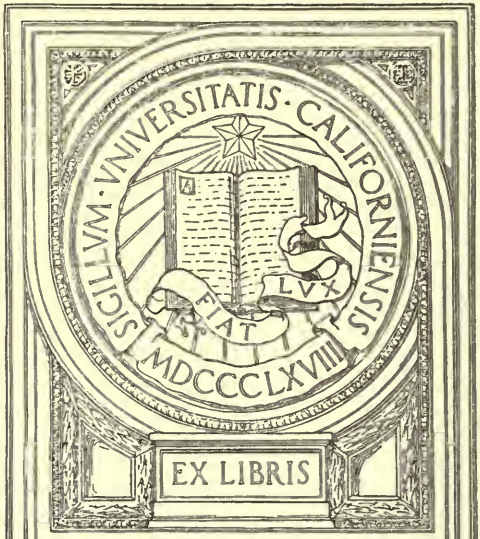

Research Publications *of the* University *of* Minnesota

Vol. VIII No. 4 ——— July 1919

Studies in the Biological Sciences

Number 3

AN INVESTIGATION OF THE LOUSE PROBLEM

BY

WILLIAM MOORE, B.A.

Associate Professor of Entomology in the University of Minnesota

AND

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Professor of Pharmacology in the University of Minnesota

L. Hekkers

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CONTENTS

FIGURES

AN INVESTIGATION OF THE LOUSE PROBLEM*

INTRODUCTION

In April, 1917, a committee, representing different departments of the University, was formed to stimulate research dealing with war problems. The subcommittee from the Medical School, at the suggestion of Professor Leonard G. Rowntree, submitted the louse problem as one which required further investigation. Accordingly, during the rest of 1917 and the early part of 1918, the question was investigated by the writers under a grant from the Research Fund of the Graduate School granted by the Regents of the University of Minnesota, but in March, 1918, at the request of Dr. Richard M. Pearce, the work was continued under the direction of the Division of Medicine and Related Science of the National Research Council. The National Research Council supplied funds for the continuation of the work, but the entire research was conducted by the authors as members of the University staff, a room and facilities being freely placed at our disposal. We wish to express our appreciation of the courtesies and assistance of Dr. Pearce and others in Washington, and our indebtedness to Dean R. W. Thatcher, Director of the Experiment Station, and to the University authorities for the privileges and coöperation they have granted us during the investigation.

In the conduct of these investigations, the entomological experiments including the laundering, fumigation, and the effects of different chemicals upon the insects have been conducted by Moore, and the chemical experiments, including the suggestion of certain of the chemicals and their synthesis where necessary, by Hirschfelder. The clinical studies were also conducted by Hirschfelder. After September 25, 1918, when Hirschfelder was called to the Chemical Warfare Service, Professor R. A. Gortner, Chief of the Division of Agricultural Biochemistry, assisted by the preparation of a few brominated compounds, and has also favored us with valuable advice throughout the investigation. Mr. S. A. Graham, of the Division of Entomology, assisted in the rearing of the lice during the earlier experiments, while Miss Anna Wentz took charge of this work in the later experiments. The willingness of both Mr. Graham and Miss Wentz to feed and care for the lice contributed largely to the success of the investigation. Another disagreeable task, that of collecting lice from the dirty garments of louse-infested individuals, was conscientiously carried out by Mr. John Burke, technical assistant in the Department of Medicine. Special credit is due to those persons who volunteered as subjects for the experiments

* Certain portions of this paper have appeared in the following publications: *Journal of Laboratory and Clinical Medicine* 3: no. 5, Feb. 1919; *Journal of American Medical Association* 71: 530-31, Aug. 17, 1918; *Ibid.* 71: 1481-82, Nov. 2, 1918; *Journal of Parasitology* 5: 61-68, Dec. 1918; *Archives of Internal Medicine* 23: 419-30.

dealing with the toxic effects of louse bites. To all who have thus helped in the investigation of this problem, we wish to express our indebtedness, and our appreciation of their assistance.

NATURE OF THE PROBLEM

The clothes louse (*Pediculus corporis*) commonly known as "gray backs," "crumps," or "cooties," has presented a most important problem in the present war. Altho hundreds of papers dealing with investigations of this problem have been printed since 1914, and innumerable methods have been tried out, lousiness is still prevalent in the armies. This condition is due not to any great resistance of the louse to ordinary measures of destruction, since there are many methods by which it may be destroyed, but rather to the inability to apply these treatments under the conditions of modern warfare. The problem, therefore, is not to find some chemical or other means of destroying lice, but rather to find some method which can be applied under the existing conditions. It is not sufficient to find simply a method of delousing, but what is required is the simplest, cheapest, and quickest method in order that with a very small amount of equipment a large number of men may be cleaned in a very short period of time. To protect men from reinfestation, a chemical is required which will not only kill lice, but will also retain its effectiveness for the longest period of time.

METHODS OF REARING LICE AND NOTES ON THEIR BIOLOGY

The primary object of this investigation was to study the possible methods of controlling lice, and hence only notes or general observations upon their biology are available. What few observations are here recorded are largely from data obtained by Miss Wentz while rearing large numbers of lice to be used for experimental purposes. Experiments designed to determine some point in the life history were often discontinued to supply lice for experiments concerning the toxicity of some chemical; hence full data upon some points were not obtained. Other workers have studied their biology more fully, and recently Nuttall[1] has gathered this information together into one paper. In some of the biological studies the lice were confined by one means or another to some portion of the body of the experimentor, thus producing conditions as nearly normal as possible. Such methods are necessary for accurate observations upon the life history, but since the present object was rather to study means of destruction, entailing the use of large numbers of lice, the incubator method of rearing them was found to give the best results. The following observations show how nearly incubator conditions correspond to more natural conditions of rearing lice.

[1] The Biology of Pediculus humanus. *Parasitology* 10:80-185. 1917.

Rearing Lice under Incubator Conditions

Methods of feeding.—The lice, after being collected, were placed on small woolen squares (1 cm. x 1 cm.) in a glass vial or an ordinary drinking glass, and kept in a small electric incubator heated by means of two small carbon bulbs. The lice were free to roam over this wool, upon which they laid their eggs.

The first problem presented was the discovery of a successful method of feeding the lice. Rabbits and guinea pigs were experimented with as hosts, by tying them to a dissecting board and shaving the hair off an area of about 5 to 6 cm. square. The lice were transferred upon the woolen squares to the bare skin of the animal, but in all cases they refused to feed. Noeller[2] claims that they will feed and breed successfully upon a pig; hence a small pig about two or three weeks old was obtained and tested in a similar manner to the rabbits and guinea pigs, but altho the lice attempted to puncture the skin, they did not succeed. Similar attempts to feed on the ear of the pig gave negative results. Nicolle, Blaizot, and Conseil[3] have experimented with the monkey as a host and find that altho the lice fed, they did not feed as well as on man. A monkey having been obtained and freed of its own parasites, an attempt was made to feed the clothes louse upon a shaved area in a manner similar to the experiments with the other animals. In this case the lice fed, but not as readily as upon human blood. Another difficulty encountered was that of securing the monkey tightly enough to prevent movements which would dislodge the lice. Owing to this difficulty and the fact that the lice did not appear to thrive on monkey blood, the monkey was finally abandoned as a source of food. In a few experiments an attempt was made to feed lice with citrated human blood enclosed in sausage skins, but this was unsuccessful. All these experiments having failed, feeding upon the human forearm was finally adopted. In the first experiments, the lice were carefully fed under a glass cover, but this was soon found to be an unnecessary precaution. During the first feeding in captivity, the lice were prone to wander away from the woolen squares, crawling about over the arm, but after being fed once or twice in this manner and being kept in the incubator between feedings, they lost this migratory impulse and as soon as the woolen pieces were placed upon the arm, moved down, fed, and then again traveled up onto the cloth. In this manner, pieces of cloth with as many as 4,000 lice have been fed on the forearm at one time without danger of the person becoming infested.

Among the persons who have fed the lice in these experiments, one person was particularly interesting, inasmuch as the lice refused to feed on his arm, merely wandering about for as long a period as one hour, after

[2] Beitrag zur Flecktyphus Uebertragung durch Läuse. *Berlin klin. Wochenschr.* 53:778-80. 1916. Abstract, *Review of Appl. Entom.* (series B) 5:33.

[3] Etiologie de la fièvre récurrente; son mode de transmission par le pou. *Ann. Inst. Pasteur* 27:204-25. 1913.

which they were transferred to another person and fed readily. Later attempts to feed the lice upon this first person were in general unsuccessful, altho occasionally a few lice were found to feed. No possible explanation of this aversion of the lice to feed upon this person was discovered, but there can be no doubt that for some reason he was objectionable to them. In other experiments it was found that the lice fed readily upon his brother.

During the earlier experiments the lice were fed but once a day and were kept in the incubator at 26°–28° C. between feedings. These conditions did not appear to be favorable and several supplies of lice died off, the males in all cases dying first, leaving females only which laid infertile eggs. Since this occurred three times and therefore can hardly be considered accidental, it would appear that the males were not able to withstand unfavorable conditions as successfully as the females. Two feedings a day were then adopted and the temperature of the incubator increased to 28°–32° C. and the relative humidity raised to 70–80 per cent, after which no further trouble was encountered. Under these favorable conditions, lice were reared in the incubator generation after generation, as many as five generations having been observed. Starting with as few as 20 lice they have increased under incubator conditions to 4,000 and would no doubt have reached a higher number if permitted.

Incubator conditions.—It has been previously mentioned that a temperature of 26°–28° C. did not prove favorable to the lice, while 28°–32° C. proved successful. Martini[4] has shown that when lice are placed upon a surface so heated that the temperature of different portions registers from 15°–35° C., the largest number of lice will congregate on the areas showing temperatures ranging from 28°–31° C.

A temperature above 32° C. has proved, in general, somewhat unfavorable to the active stages, but not to the eggs. Eggs easily withstand a temperature of 35° C., hatching in a shorter period of time at this higher temperature. A low relative humidity was found unfavorable to both the active stages and the eggs, the effect being more noticeable when the temperature was above 30° C. than at a lower temperature. Sixty to eighty per cent relative humidity was most favorable to development, while a higher relative humidity, 90 per cent or above, was injurious, in fact more injurious than a low relative humidity. In one test, a relative humidity of 68 per cent was recorded in the space between the skin and the undershirt. With too high a relative humidity, the faeces of the lice remained wet and were smeared over the walls and bottom of the container, while the lice which died under these conditions usually turned black. The right degree of humidity was maintained by placing a wet towel or a dish of wet sphagnum in the incubator. This additional moisture

[4] Zur Kenntnis des Verhaltens der Läuse gegenüber Wärme. *Zeitschr. für angewandte Entomologie* 4:34-70. 1917.

TABLE I

INCUBATION PERIOD OF EGGS

No. of eggs	Hatching occurred after days															Temperature (Centigrade)	Per cent hatched
	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20		
50	..	..	..	..	..	..	..	11	17	6	7	1	..	..	..	26°–28°	84
36	..	..	..	..	..	..	..	..	2	8	1	12	2	1	1	26°–28°	75
15	..	..	..	..	..	..	..	1	..	..	..	1	2	2	..	26°–28°	40
22	..	..	..	..	..	..	..	..	..	1	3	1	1	..	..	26°–28°	27.2
27	..	..	..	..	..	..	..	..	..	1	4	1	..	..	..	26°–28°	22.2
36	..	..	..	..	..	..	..	..	4	4	2	1	..	..	..	26°–28°	30.5
42	..	..	..	..	..	8	15	6	4	..	..	..	..	..	..	28°–30°	78.5
65	..	..	..	..	2	12	30	9	7	..	..	..	..	..	..	28°–30°	90.8
48	..	..	..	4	15	17	11	..	..	..	..	..	..	..	..	30°–32°	98
66	2	..	38	11	..	..	..	..	..	..	..	..	..	..	..	26°–33°	77.3
67	1	1	24	8	..	..	..	..	..	..	..	..	..	..	..	26°–33°	50.7
67	..	2	20	9	..	..	..	..	..	..	..	..	..	..	..	26°–33°	46.2

was very necessary during the winter months, when the humidity of the laboratory was quite low, while during the summer only a small quantity of water was necessary. The need for these moist surfaces in the incubator may have been due to the type of incubator used, there being a constant circulation of air through a small opening near the bottom and a similar opening in the top. This tended to reduce the humidity.

An effort was made to determine the correct percentage of moisture favorable for development by placing the vials with the lice in closed containers with different dilutions of sulphuric acid, but since it was necessary to open the container twice daily at feeding time, it is doubtful if the humidity within the container could adjust itself quickly enough to give definite results; at least no definite data were obtained.

Life history under incubator conditions.—Observations upon the life history of the louse were made from time to time during the regular experiments, and the tables given are compiled from these data. The eggs required from 6 to 20 days to hatch; 6 to 9 days, or rather 8 to 9 days, representing the incubation period under favorable conditions of temperature and humidity, while under a lower temperature and less favorable conditions the time required was 13 to 20 days. (Table I.) The results under good incubator conditions compare favorably with the 6 to 8 days required for the hatching of the eggs kept near the human body in Nuttall's experiments.[5]

When fed twice daily, 25 young just hatched from the eggs were successfully reared to adults in 10 to 16 days, compared with the 14 to 23 days required under less favorable conditions. (Table II.) This period is somewhat longer than the 7 days obtained by Nuttall[6] with lice worn continuously. The difference represents the unfavorable influence upon the development of the louse of feedings 8 to 14 hours apart. This delay in development is not serious, since in the experiment all of the 25 lice were raised to maturity, with no more than customary attention. About one day was required between the last moult and the laying of the first eggs.

TABLE II

LENGTH OF INSTARS

No. of lice	1st moult after	2nd moult after	3rd moult after	Total from egg to adult	Temperature (centigrade)	Feeding
25	2–4 days	4–6 days	4–6 days	10–16 days	29°–32°	2 in 24 hrs.
46	4–8 days	.....	...		26°–29°	2 in 24 hrs.
26	.....	5–8 days	...	14–23 days	26°–29°	2 in 24 hrs.
18	.....	.....	5–7 days		27°–29°	2 in 24 hrs.

No data are available concerning the percentage of the different sexes, but general observations give the impression that females were more

[5] The Biology of Pediculus humanus.

[6] *Ibid.*

numerous than males. Data concerning the longevity of the adults are also incomplete. One female required 16 days from hatching until the first egg was laid, after which she lived 26 days, laying in all 80 eggs. In other experiments 40 and 41 days were noted as the total life of the lice from hatching to death; while not more than 4 eggs were laid in any one day by a single female. Here again are shown the results of irregular feeding periods, since Nuttall[7] obtained as high as 12 eggs in one day with an average of 9.7 eggs per day, the total egg production of one female, when kept continuously upon the human body, reaching 272 eggs. Under such conditions the lice feed many times a day and do not gorge themselves with blood as they do when fed twice daily; hence there is more room in their body for the development of the eggs.

Lice may lay eggs even when not kept in an incubator but the egg production diminishes greatly with the lower temperatures. Three sets, one in the incubator, one in the laboratory, and one in the basement, were kept for six days, the data being given in Table III. Eggs laid under such conditions may be fertile and will hatch in the incubator, but eggs laid in the incubator and kept in the basement at 17°–23° C. never hatched, altho they were observed for three or four months.

In general the eggs obtained under the artificial incubator conditions were fertile, but sometimes the percentage hatching ran very low, possibly in part due to infertile eggs and in part to unfavorable hatching conditions. (Table I.)

Changes in appearance following death.—One of the chief causes of death appears to be overfeeding following fasting. Lice may survive long periods without food if kept at a low temperature, while at higher temperatures this period is much reduced. Lice were collected from infested individuals and kept in a laboratory heated to 20° C. for various periods of time without feeding. One set left for 40 hours showed 1 had moulted, 4 eggs had been laid and 1 immature louse and 1 male were dead, while 5 females, 5 males and 10 immature lice fed readily. A second lot fasted for 58 hours, during which time 6 eggs were laid, 1 immature louse had died, while 8 immature lice, 8 males, and 7 females survived and fed. A third set left for 88 hours resulted in the death of 3 females, 4 males, and 8 immature lice, while only 3 females and 1 immature louse survived and fed. Six eggs were laid during the 88 hours.

TABLE III

INFLUENCE OF TEMPERATURE ON EGG PRODUCTION

Location	No. females	Temperature (Centigrade)	No. days	No. eggs laid	Average per female per day
In incubator.....	18	27°–31°	6	306	2.8
In laboratory.....	15	15°–27°	6	48	.53
In basement.....	15	17°–23°	6	5	.055

[7] *Ibid.*

Frequently after such a fast or even after one of 24 hours under incubator conditions, the lice during or shortly after feeding will turn bright red, the color even extending into the legs. Such lice always die within a few hours. When a louse feeds after fasting, it takes so much blood that the remains of its last meal are forced out of the intestine, together with considerable quantities of undigested blood. If lice are thus able to remove the remains of their last meal, they retain their normal color and do not die as a result of excessive feeding. In some lice, particularly when kept under dry conditions, the contents of the hind gut seem to harden, and are not readily forced out during feeding. It is such lice which during the feeding or shortly afterward turn red and later die. The cause of death appears to be the rupture of the intestine due to the large quantity of blood taken in, while the hind gut is plugged with the hardened remains of the previous meal.

Lice destroyed by many different methods turn red after death, but this redness appears different from that following overfeeding. Lice destroyed by most chemical means thus turn a red or reddish brown color, apparently because of the escape of the blood through the walls of the intestine. Possibly the walls of the intestine are weakened by an autolytic action of enzymes which have not been destroyed. Lice killed by boiling water, which destroys the enzymes, do not turn red after death, but on the other hand heat coagulates the proteins and the blood and may in this manner prevent the louse from turning red. Many lice, killed by a temperature of 45° C., which should coagulate the proteins, turn red or reddish brown. Lice dying with little or no food in their intestine do not turn red nor do lice turn red when killed by a slowly acting poison requiring 24 to 48 hours to kill. This may be due to the fact that in the presence of such a poison lice usually fail to feed.

In the presence of rapidly acting poisons all movements of the lice cease, producing what Nuttall[8] calls sham death; since if the lice are then removed from the presence of the poison they usually revive within 10 to 12 hours. This suspended animation, as will be shown later, appears to be due to the closing of the tracheae to keep out the poison, resulting in the lice becoming stupified from lack of oxygen. If exposed for a longer period to the action of the poison, they die and assume a reddish coloration.

PATHOLOGICAL EFFECTS OF THE BITE OF THE CLOTHES LOUSE

Observations of other workers.—Typhus fever, European relapsing fever, and more recently, trench fever have been shown to be carried by the clothes louse, while minor infective diseases, such as favus, pityriasis, and

[8] The Biology of Pediculus humanus.
Combating Lousiness among Soldiers and Civilians. *Parasitology* 10:411-586. 1918.

impetigo contagiosa are also known to be conveyed in a similar manner.[9] Prurigo, prurigo senilis, urticaria, and porrigo, all pathological conditions caused by lice, are grouped together by the Editor of the *British Medical Journal*[10] under the general term Pedicularia. Melanodermia may also appear in the vicinity of the bites. All of these conditions may be considered as secondary effects due to some organism transmitted from host to host by lice, or to the direct toxic effect at the site of the bite followed in some cases by scratching, causing a skin rash such as urticaria. Payne,[11] however, noted a rise in temperature apparently due to a general toxic effect of Phthirus pubis. It has been demonstrated experimentally that this insect causes maculae caeruleae, and Duguet[12] has shown that these spots may also be produced by the inoculation of that portion of the body of the louse in which the salivary glands are located. Jamieson[13] records two clinical observations of young persons infested with clothes lice having a temperature of 103° F. in one case, and 106.2 to 106.4° F. in the other case, in each of which the temperature returned to normal after the patient was bathed and freed of lice. Reviewing the literature dealing with the toxic effects of louse bites, Nuttall[14] sums up as follows: "Apart from the maculae, Phthirus, like P. humanus, fleas, and mosquitoes, may cause a febrile condition owing to skin irritation, altho this appears to be rare; with the removal of the lice, the fever promptly subsides."

General observations.—In view of the above statements, the following observations were both surprising and interesting. Following the failure, in the spring of 1917, to use animals as hosts, a person designated as A undertook to feed them on the forearm. Altho fed but once a day, a severe case of urticaria developed; hence other persons were given an opportunity of assisting in this work. Among those offering assistance at this time, were C and D, both subjects used in the later experiments. C fed the lice 2 or 3 times a week during this period, but D was used only 2 or 3 times in the entire period of 3 to 4 months. The work continued in this manner until August, 1917, during which time no one person fed the lice more than 3 times a week, and at no time were there more than 400 lice. A person designated as B then took up the work and continued it until December, 1917, during which time all the lice, not exceeding several hundred at any one time, were fed by the same person. No noticeable symptoms of

[9] The Part Played by Pediculus humanus in the Causation of Disease. *Parasitology* 10:43-79. 1917.

[10] Editorial, Pedicularia. *Brit. Med. Journ.* 2:1427. 1869.

[11] Maculae caeruleae and Other Symptoms Produced by Pediculi pubis. *Brit. Journ. Dermatol.* 2:209-12. 1890.

[12] Sur les taches bleues; leur production artificielle leur valeur séméiologique. *C. R. Soc. de Biol.* 32: 69-78. 1880.

Expérience et recherches nouvelles sur les taches bleues. *Ibid.* 34:617-22. 1882.

[13] On Some Rarer Effects of Pediculi. *Brit. Journ. Dermatol.* 1:321-27. 1888.

[14] The Part Played by Pediculus humanus in the Causation of Disease.

illness developed at this time. Work was temporarily discontinued from December, 1917 until March 12, 1918, when it was again started; B feeding the lice on the forearm twice daily. The number of the lice being small, not more than 50, the local irritation was reduced to a minimum, by changing the feeding area from one arm to another, and by washing the arm immediately after feeding with 95 per cent alcohol followed by an application of a mixture of ½ glycerine and ½ ammonia. During April, the number of lice increased, and the first signs of a possible intoxication due to their bites were noted. B described the symptoms as follows: very nervous, extremely tired with great drowsiness in the early afternoon, sleeplessness during part of the night, at least to some extent due to burning and itching of the arms. A steady, dull ache at the base of the skull, sometimes extending to the eyes, was experienced, accompanied by chills and aching as if coming down with an attack of "grippe." Apparently a fever developed, but since no temperature records were taken, this can not be substantiated. This feeling of fever lasted 3 days, during which time a rash similar to measles appeared over the shoulders, chest, and neck, lasting about one day. The illness occurred between April 15 and 30, but since it was not associated with the louse bites, the data are very meager. About April 20, due to B's illness, C undertook to feed the lice. Whereas B had started with a small number of lice which gradually increased, C started with from 700 to 800, and almost immediately a general tired feeling or aching similar to that experienced by B was noted. In the calf of the legs, along the shin bones, and the soles of the feet, particularly underneath the toes, this pain became sufficiently intense to interfere with sleep until late in the night. An irritable and pessimistic state of mind developed. May 7, an illness resulted, the symptoms being very similar to "grippe" but accompanied by a rash, over the shoulders and abdomen, similar to German measles. German measles being prevalent in the community at that time, the illness was considered to be this disease and after remaining in bed for several days, C returned to work and again took up the feeding of the lice.

The general symptoms previously noted again developed with increasing intensity, the number of lice having increased to about 1,200 by May 15. May 28, C was again ill and the family physician having been called diagnosed the illness as "grippe." The following day, a rash, quite typical of German measles, developed but other symptoms of measles were absent. The heart was normal, pulse about 90, temperature varying from 100° to 102° F. A blood count showed a normal number of leucocytes and red blood cells. A severe headache was experienced, accompanied by a general aching, often intense, in the joints. Dr. A. D. Hirschfelder saw the patient and considered that the illness was not German measles nor was it "grippe," but thought it might be trench fever. Glandular enlargement was absent

and no enlargement of the spleen was noted. Recovery was complete except for a general weak condition by June 4.

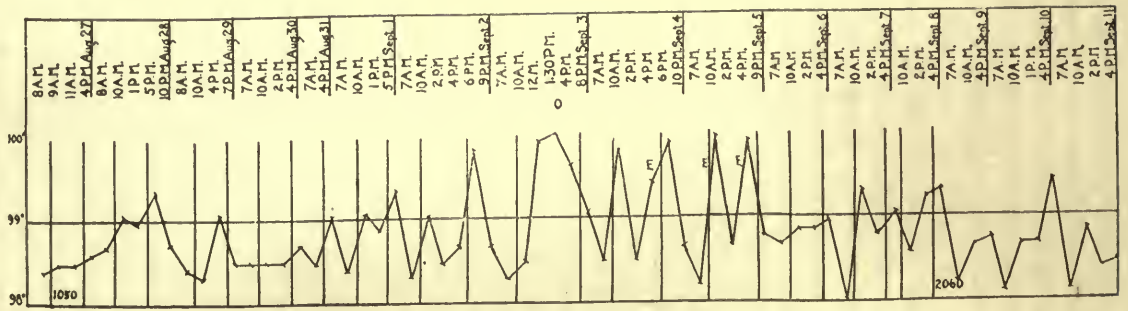
June 6, the lice, numbering about 800 adults, were again fed by C, but no symptoms of illness were manifest until about June 17 when the number of lice had increased to about 1,800, due to the hatching of young lice. Symptoms similar to the two previous illnesses then developed, but work was discontinued June 28 before they were serious enough to necessitate remaining in bed. The 29th and 30th were spent in the open and the symptoms gradually disappeared.

Clinical studies.—The observations given above indicate that a macular erythematous, skin eruption, somewhat resembling that of measles or German measles, distributed over the chest, back and abdomen, may occur in a normal individual who allows lice to feed upon the skin of the forearm only. This eruption was accompanied by general lassitude, headache, and peculiar pains in the calf of the legs and the soles of the feet, particularly under the toes. Unfortunately the association of these symptoms with louse bites was not at first considered; hence definite data of the illnesses are not available. A series of clinical studies was therefore planned at the suggestion of Major R. M. Pearce to determine whether the previously recorded observations represented a peculiarity of the individual upon whom the lice had fed, or whether it might be regarded as a general phenomenon. There naturally arose the question as to whether the condition represented sporadic typhus fever, trench fever, or some other infection, or a reaction to toxic products derived from the louse. Such a reaction might represent either a primary intoxication or a state of anaphylaxis, but in view of the fact that one of the individuals tested had never been bitten by lice before, the rôle of anaphylaxis seems unlikely. It is a striking fact, however, that in this indiyidual none of the skin eruptions appeared. It is possible that the skin manifestations may represent an anaphylactic response, even if the general toxemia does not.

Four perfectly healthy young men, members of the Faculty of the Department of Agriculture of the University of Minnesota, volunteered for the experiments. They were examined by Dr. A. D. Hirschfelder and found to be normal, except, in some cases, for the enlargement of a lymph gland here and there. The total blood counts, haemoglobin, lymphocytes, and differential counts were taken and the two latter repeated daily or at frequent intervals. The Wasserman reaction was taken by Dr. W. P. Larson and found to be negative in each case.

The lice used in the experiments were raised from eggs and had been fed only upon the persons who were the subjects of these experiments and who were otherwise healthy, and upon one other perfectly healthy individual. According to the work of Strong and his collaborators[15] and

[15] Report of Progress of Trench Fever Investigation. *Journ. Amer. Med. Assn.* 70:1597-99. .



Curve 1

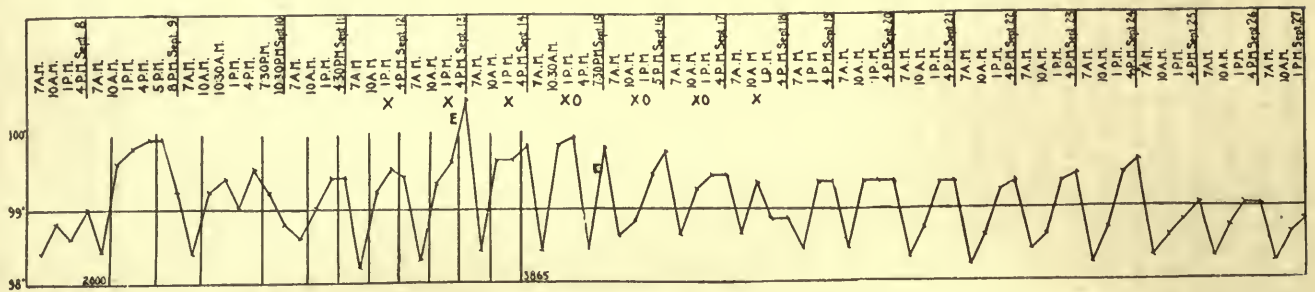
Rectal temperature of C. Vertical lines representing louse feedings, the number of lice being marked on the first and last lines. O represents the occurrence of a rash and E when exercise was taken. The line at 98. 95° denotes the average rectal temperature

Byam and his collaborators[16] these lice could not therefore be carriers of trench fever. No opportunity existed for inoculation with the faeces of the louse, since immediately after feeding, the arm was either carefully washed with soap and water and then bathed with alcohol, or was bathed with alcohol and then treated with ammonia and glycerin.

Experiment 1.—C, who had fed lice from time to time for the past year and a half and who had developed the symptoms noted above, started on August 27 the feeding of 1,050 lice twice a day. Health normal at this time. The rectal temperature remained normal until September 2, during which period the lice were slowly increasing in numbers. They failed to produce any reaction at the site of the bites other than a faint macular erythema, altho all the feedings were on the palmar surface of the left forearm. September 3 a faint rash, composed of semilunar and crescentic macules, 2 to 3 millimeters in size, resembling those of a fading measles or German measles occurred. More or less biparietal and vertical headache was present accompanied by a sort of dazed or confused sensation and a general lassitude. Blood cultures, aerobic and anaerobic, were negative. No enlargement of the glands or of the spleen could be detected. Following September 3, altho feedings were continued with an increasing number of lice until September 8, when they numbered 2,060, the fever diminished, but would always rise sharply following exercise even resulting from walking a few blocks. Discontinuing the feeding on September 8, the temperature returned permanently to normal. (Curve 1.)

Experiment 2.—A was the subject of the second experiment. Altho he had fed lice during the early experiments of 1917, he had not fed them since August, 1917. At that time no symptoms of illness were manifest but considerable local irritation had been experienced. September 9, the experiment was started with 2,000 lice. Considerable irritation resulted at the feeding site, an irregular red macular and maculo-papular eruption being present, a sharp rise in temperature following within an hour of the first feeding. On the fourth day, enlargement of the lymph glands of the axilla was noted and by the seventh day the inguinal and submaxillary glands also enlarged and became quite tender. A well-defined rash similar to that noted in the previous experiment was present over the chest, back, and particularly over the abdomen, lasting for three days. Blood cultures were negative. Feedings were discontinued on the 14th when the lice numbered 3,865. Altho the temperature diminished after feeding was discontinued, it was not until the 25th that it could be said to be normal. No general lassitude was experienced in this case, but the patient was weak and his mind confused during the period from September 12 to 18. Blood

[16] Trench Fever: A Report of Clinical Observations and Research as to the Etiology, Pathology, Prophylaxis and Treatment of Trench Fever among Troops. *Journ. Amer. Med. Assn.* 71:21-26; 110-13; 188-92.

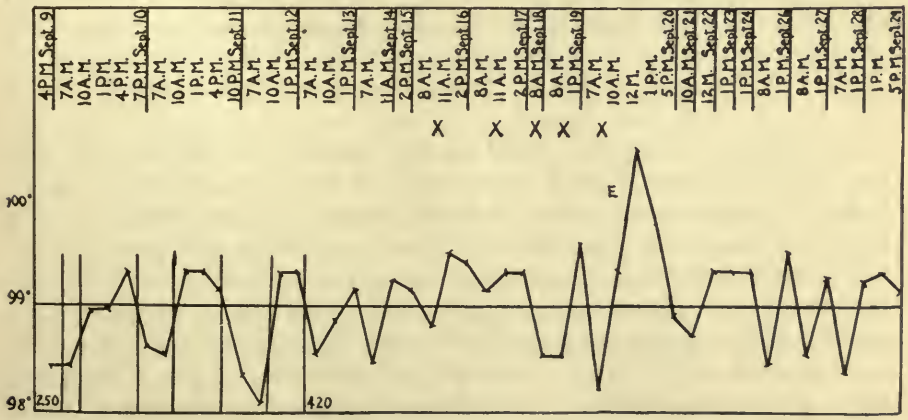


Curve 2

Rectal temperature of A. Markings same as in Curve 1 with the addition of an X to represent swollen glands

counts taken throughout the experiment failed to show any abnormal change. On September 27, after the temperature had been normal for three days, A started a canoe trip, during which fever was experienced, but having no thermometer, the exact temperature is not known. Immediately upon his return, 7:30 p.m., September 30, the temperature was taken and found to be 102.7° F. The lymphatic glands previously affected again became enlarged. For five days after his return his temperature remained at 100° to 101.7° F., during which time the swelling of the glands gradually subsided. His family physician, who had been called, found no symptoms other than a fever and the glandular enlargement. (Curve 2.)

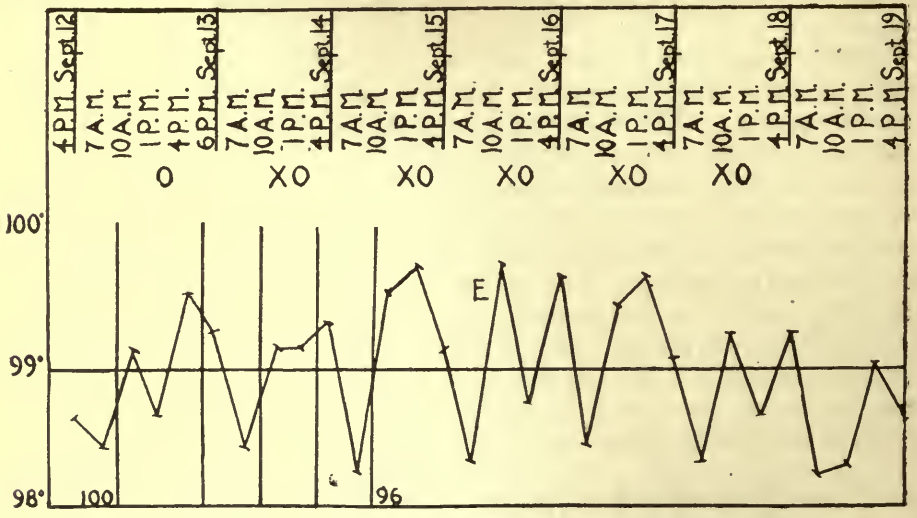
Experiment 3.—E, a person who had never previously fed lice, was the subject of the next experiment. Two hundred and fifty lice were used in this experiment. After two feedings a rise in temperature was experienced. Feedings were discontinued on the fourth day, when the lice numbered 420. His temperature, however, remained slightly above normal and glandular enlargement was noted on the seventh and eleventh days. Even slight exercise gave a decided increase in temperature similar to that noted in the previous experiments. No rash or other symptoms developed, and on the 19th, due to the development of a cold, the experiment was closed, although the temperature had not returned to what might be considered normal. (Curve 3.) In the case of E, faint, pink macules appeared at the site of the bite directly after feeding, but soon faded and after a few hours no evidence was apparent that the arm had ever been used to feed lice.



Curve 3
Rectal temperature of E. Markings same as in Curves 1 and 2

Experiment 4.—D, who had fed the lice a few times during the summer of 1917, was used in this experiment, the lice numbering 100 at the start

and 96 at the close of the experiment three days later. Immediately after the first feeding his temperature rose and within seven hours a rash, similar to that encountered in the previous experiments, was discernible. The following day glandular enlargement was noted, and by the following day the glands had become tender. Altho the feeding was continued for only three days, the rash lasted six days, the glandular enlargement five days, and seven days were required for the temperature to return to normal. (Curve 4.) Blood counts as in the previous experiments did not show abnormal numbers of either leucocytes or red blood cells.



Curve 4
Rectal temperature of D. Markings same as in Curves 1 and 3

Experiment 5.—F was injected subcutaneously under the arm with 3 c.c. of blood taken from A at the height of his illness. Within 48 hours, a definite rise in temperature to 99.5° accompanied by headache and a mild sore throat was experienced. Diffuse, small rales were present in his chest; but this reaction was probably due to an epidemic of "colds" prevalent at the time, rather than distinctly due to anything traceable directly or indirectly to the louse. The following day, his temperature was normal and remained so for the two weeks he was under observation. This phase of the subject needs further investigation, but due to the opening of college and to the epidemic of influenza, it was impossible to obtain more subjects for experimentation.

Except C, who may be considered to have developed a certain degree of immunity, every individual bitten showed a prompt rise in temperature shortly after the first feeding. The same individuals showed a well-defined

enlargement of certain of the lymph glands, while in three out of four of the subjects, a well-defined rash resembling fading measles or German measles occurred. The rash was not very striking and yet was definite enough to be seen without difficulty when it was at its height. The macules disappeared on pressure. They were distributed over the chest, back, and upper abdomen, and in no case appeared upon the face, neck, arms, or lower limbs. The rash was always most distinct and persisted longest in the region between the nipples and the lower costal margins.

In none of the individuals was the spleen palpable nor was its outline, determined by both light and auscultatory percussion, sufficiently enlarged to be definite. Aerobic and anaerobic blood cultures taken when the fever was at its height were negative.

The fact that the condition was produced by lice which had never bitten diseased individuals, and that no opportunity existed for inoculation with the faeces of the louse, as well as the negative character of the blood culture, point against either typhus or "trench fever." The absence of positive blood cultures, leucocytosis, and increases in polymorphonuclear leucocytes, as well as the absence of any foci of pyogenic infection at the site where the lice fed, rule out simple pyogenic infection.

The fact that two of the subjects, who had definite papular eruptions at the site of feeding, had also fed lice for a certain period of time a year before, while one person (E), who had never fed lice before, had no skin eruptions whatever, raises once more the question of anaphylaxis as a possible contributory factor in the symptom complex. That anaphylaxis was not the only factor, however, is proved by the fact that subject E, too, had fever and glandular enlargement as did the others.

While it can not be regarded as proved conclusively, the results of the above experiments point strongly toward the presence of a substance in the louse sufficiently toxic to give rise to a generalized skin eruption and mild fever. This may or may not be protein in nature. It is however quite clear that for the general health of the individual the bites of lice, even when "home grown," are not an indifferent matter, but greatly impair his health and bodily vigor. It becomes obvious from these experiments that men who are subject to louse bites have a lower mental and bodily vigor, and that other things being equal, a louse-free army would be considerably better fighting men than would the same army infested with lice.[17]

[17] Recently Dr. Walter C. Alvarez, of San Francisco, has communicated to us a case in which a man about 55 years of age, very heavily infested with Phthirus and Pediculus, was freed of his parasites in a county hospital. The patient at the time ran a low-grade fever, and after being cleaned, in spite of all efforts to build him up, died. An autopsy showed nothing to explain his decline and death, hence it may have been due to the toxic effect of the lice.

METHODS OF CONTROL OF THE CLOTHES LOUSE

Garment Disinfestation

Methods of controlling the clothes louse may be roughly divided into two main divisions; first, the destruction of the lice and their eggs in the clothing, and second, the destruction of the lice on the person and the protection of the individual from reinfestation. If the first method is thoroly and regularly carried out, and an effort is made to keep infested individuals segregated, the second method becomes unnecessary. Under the conditions existing in the present war, the regular and thoro disinfestation, or lousing, has not been possible. Not only did the men often go for long periods of time without an opportunity of bathing and having their clothing disinfested, but even when such an opportunity was offered, the time given to the work was generally too short to carry out a thoro disinfestation of all clothing. Such being the case, soldiers' garments coming to the laundry units near the front were often, if not always, infested with both lice and their eggs, and it became desirable to know the value of the ordinary steam laundry processes in garment disinfestation. The object of the laundry investigation was to determine to what extent these processes were destructive to both lice and eggs and, should they prove to be inefficient, what slight alterations could be made in the regular routine to make them effective.

LAUNDRY PROCESSES

Through the courtesy of Mr. J. Clair Stone, Manager of the Elk Laundry, Saint Paul, one of us (Moore) was able to study the processes encountered in the washing of regulation army clothing. The clothing may be divided into 3 types; rough cotton goods (including cotton underwear), cotton khaki wear, and woolen goods (including garments part wool and part cotton). Altho the procedure differs somewhat in different steam laundries, it may in general be outlined as follows:

COTTON GOODS

Baths	Temperature	Time (minutes)
1st water	100° F.(38° C.)	5
2nd neutral soap	180° F.(82° C.)	15
3d " "	180° F.(82° C.)	15
4th soda bath	130° F.(54° C.)	10
5th water	130° F.(54° C.)	5

Cotton goods are dried in the hot air tumbler at a temperature of 150° F. (65.5° C.) to 190° F. (87.7° C.) until quite dry. Time about 20 minutes, depending upon the load.

COTTON KHAKI

Baths	Temperature	Time (minutes)
1st water	100° F.(38° C.)	5
2nd neutral soap	120°–130° F.(49°–54° C.)	15–20
3d water	130° F.(54° C.)	5

Dried in the hot air tumbler at 150° F. (66° C.) to 180° F. (82° C.) until just sufficient moisture is left in the garment that it may be pressed. Time about 10 to 15 minutes, depending upon the size of the load. Pressed in the universal press.

WOOLEN GOODS

Baths	Temperature	Time (minutes)
1st neutral soap	110°–115° F.(43°–46° C.)	15
2nd water	110°–115° F.(43°–46° C.)	3

Woolens are dried at room temperature and never in the hot air tumbler.

The first important point to determine was what effect the temperature encountered would have upon the lice and nits. Data were available from the work of other investigations, giving an indication of what results might be expected. The following table was taken from a compilation of Nuttall:

IMMERSION OF EGGS IN HOT WATER

Temperature	Time	Result	Observer
192° F.(88° C.)	15 sec	Killed	Nuttall
169° F.(76° C.)	30 sec	"	"
158° F.(70° C.)	10 sec	"	"
150.5° F.(67° C.)	1 min	"	"
140° F.(60° C.)	5 min	"	"
140° F.(60° C.)	5 min	"	Widmann
131° F.(55° C.)	10 min	"	"
131° F.(55° C.)	30 min	"	Bacot
129° F.(54° C.)	10 min	"	Nuttall
121.5° F.(50° C.)	15 min	"	Widmann
112.5° F.(45° C.)	15 min	Not killed	"
104° F.(40° C.)	1 day	" "	"

EXPOSURE OF EGGS TO DRY HEAT

Temperature	Time	Result	Observer
124° F.(51.5° C.)	15 min	Not killed	Experiments of Capt. Orr, Canadian A. M. C., and Bacot
127° F.(53° C.)	15 min	Not killed	
130.5° F.(55° C.)	30 min	Killed	
132.5° F.(56° C.)	20 min	Killed	
134° F.(57° C.)	30 min	Killed	
152° F.(57° C.)	15 min	Killed	

Effect of laundry processes.—In my experiments it was found that the quantity of soap used varied somewhat, due to the hardness of the water. Sufficient soap was added to the water to give a good suds. It was found that with the water used in the experiments recorded below, 1 gram of ivory soap (neutral) and ⅓ gram of soda added to 265 c.c. of water furnished the desired suds. Inasmuch as the eggs are more difficult to destroy than the active stages, particular attention was paid to them. All the eggs were from lice collected from infested clothing, and kept in an incubator heated to 28°–32° C. The eggs were laid upon small squares of cloth during the week of July 27 to August 2 in Experiments 1–6 and from July 27 to August 7 in Experiments 7–12. Each piece of cloth therefore represented eggs in different degrees of development.

Exp. 1. Control set. 42 eggs. 78½ per cent hatched.

Exp. 2. Woolen goods treatment. Soaked in suds heated to 110°–114° F. (43°–45° C.) for 15 minutes. Rinsed in water of same temperature for 3 minutes, dried on a piece of filter paper and returned to the incubator. 65 eggs, 92 per cent hatched.

Exp. 3. Khaki wear treatment. Soaked in suds heated to 121°–126° F. (49°–52° C.). Avr. Temperature 123° F. (51° C.) for 15 minutes. Rinsed in water 123° F. (51° C.) for 4 minutes. Dried and returned to incubator. 38 eggs, 39 per cent hatched.

Exp. 4. Khaki wear treatment. Same as Exp. 3 except treatment was for 30 minutes. 45 eggs, 0 per cent hatched.

Exp. 5. Cotton goods treatment. Soaked in suds at 170°–186° F. (77°–86° C.). Avr. temperature 179° F. (82° C.) for 30 minutes. Rinsed in water 130° F. (54° C.) for 5 minutes. Dried and returned to incubator. 52 eggs, 0 per cent hatched.

The following experiments were conducted to determine the effect of treatment in the hot air tumbler and pressing in the universal press upon the eggs of the louse.

Exp. 6. Eggs placed in pocket of a bathrobe in the hot air tumbler carrying a heavy load. Tumbler had been running for 5 minutes before eggs were placed in it. Eggs in the tumbler for 10 minutes and garments were quite moist when eggs were removed. Eggs replaced in incubator after treatment. 88 eggs. 0 per cent hatched.

Exp. 7. Control 48 eggs. 100 per cent hatched.

Exp. 8. Cloth upon which the eggs were laid wet and then placed in the pocket of a pair of khaki trousers which was tumbled with other garments for 15 minutes. Load light and removed while still damp. Regular practice of drying khaki wear. 146 eggs. 0 per cent hatched.

Exp. 9. Eggs placed in pocket of partly dried bathrobe. Light load of clothing, tumbled for 10 minutes. 53 eggs. 0 per cent hatched.

Exp. 10. Same as Exp. 9 but tumbled for 15 minutes; 73 eggs. 0 per cent hatched.

Exp. 11. Same as Exp. 10, but tumbled for 20 minutes; clothing quite dry when removed. Regular cotton goods treatment. 57 eggs. 0 per cent hatched.

Exp. 12. Cloth with eggs placed under pocket of a pair of khaki trousers being pressed in the universal press. After treatment removed to incubator. 61 eggs. 0 per cent hatched.

The recorded experiments on the effect of soap suds at different temperatures on the eggs of the lice would lead one to suppose that active stages would also be destroyed in those experiments where the suds had proved destructive to the eggs. To verify this, the following experiments were conducted:

Exp. 13. Twelve recently fed lice in different stages of development were dipped in suds at 110°–114° F. (43°–45° C.) for 15 minutes, rinsed in water at 112° F. (44° C.) and dried on filter paper. All revived within a few hours.

Exp. 14. Same as Exp. 13, but suds at 122–126° F. (50–52° C.). Avr. temperature 124° F. (51.1° C.) for 15 minutes. All lice killed by treatment, turning reddish brown within 5 hours.

Exp. 15. Same as Exp. 14 but exposure lasting 30 minutes. All lice killed.

The experiments show that the washing of rough cotton goods at 180° F. (82° C.) for 15 or 30 minutes will destroy the lice and their eggs. If by any chance an egg should escape destruction in the washing process it would later be destroyed during drying in the hot air tumbler. Washing cotton

khaki clothing at a temperature of 120°–130° F. (49°–54° C.) for 15 minutes would prove destructive to the active stages, but would not completely destroy the eggs. Washing for 30 minutes, however, proved destructive to the eggs. Drying khaki uniforms in the hot air tumbler would also destroy any eggs that might have escaped the action of the hot suds. Pressing in the universal press was also effective, but this treatment can not be relied upon to destroy all the eggs in an infested suit, as portions of the uniform may not be touched. Neither the lice nor their eggs were destroyed in the woolen goods by the regular washing, and since they are dried at room temperature, the problem resolved itself into devising some method of laundering woolens that would prove destructive. The first method which suggested itself was the treatment of the woolen goods in the hot air tumbler for 10 to 15 minutes before they are washed and while still dry. Nuttall[18] claims "that the moderate degree of dry heat necessary to kill vermin will not prove injurious to wool but that high temperature, 104° C., acting for 4 hours while but slightly yellowing white flannel, does not affect its tensile strength, but if exposed to 127° C. for half an hour, flannel yellows and becomes brittle." This method, however, is open to two objections; namely, the danger of reinfestation of clean garments from handling garments infested with active stages in the vicinity of the tumbler, and the coagulating effect of the hot air on stains of blood, excreta, and other proteins, which may be present on garments before they are washed. Both these objections would be removed if the garments were first washed in such a manner as to destroy the active stages. The garments after drying could then be run in the tumbler to destroy all eggs which had escaped destruction during the washing.

The effect of soap suds on lice.—In experiments on contact insecticides, Moore and Graham[19] had found that, where the insecticide possessed both wetting and spreading properties, it entered the tracheae of the insect, thus bringing about death. Fat solvents, oils, etc., together with soap, possessed such properties. Ivory soap, however, was found to possess great cohesion, thus preventing it from readily entering the tracheae. By raising the temperature of the solution or diluting it with water, the cohesion was reduced. From these results, it was not apparent why the suds used in the previous experiments at a temperature of 110°–114° F. (43°–45° C.) should not have killed the active stages of the lice. The following experiments were conducted to throw more light on this point.

Exp. 16. Lice not fed for 5 hours were dipped in a solution containing 1 gram of ivory soap to 100 c.c. of water colored blue with trypan blue. Temperature 108°–115° F. (42°–46° C.). Lice removed in 15 minutes and examined by mounting

[18] Combating Lousiness among Soldiers and Civilians.

[19] Physical Properties Governing the Efficacy of Contact Insecticides. *Journ. of Agri. Research* 13: 523-38. 1918.

in alcohol on a glass slide, but no trace of the colored soap solution could be found in the tracheae.

Exp. 17. Same as Exp. 16, but soap solution 1-250 c.c. results negative.

Exp. 18. " " " " " " " 1-500 c.c. " "

Exp. 19. " " " " " " " 1-750 c.c. " "

Exp. 20. " " " " " " " 1-1000 c.c. " "

Exp. 21. Same as Exp. 18, but soap solution at a temperature of 122°–132° F. (50°–56° C.). Lice were killed by the treatment but no trace of the solution could be found in the tracheae.

Exp. 22. Lice placed in soap solution 1-500 at room temperature at 8:13 a.m. and removed at 3:30 p.m. No trace of soap solution in tracheae of specimens examined. Lice divided into two lots; one rinsed in water; the other not rinsed. Both sets revived within an hour.

Since it appeared impossible for the ivory soap solution to enter the tracheae, a solution of Castile soap with much lower cohesion was used but similar negative results were obtained. Soap solutions having failed to enter the tracheae, the question arose as to whether fat solvents or oils could penetrate.

Exp. 23. Lice dipped in xylene stained with Sudan III were examined at the end of 5 minutes but no trace of the stain could be found in the tracheae.

Exp. 24. Lice dipped in ether stained with Sudan II. One specimen examined after 2 minutes but no stain was detected. Stained ether was found in few tracheae of a louse which had been dipped in the ether for 5 minutes, but none was found in a specimen removed after 8 minutes.

Exp. 25. Twelve lice dipped in ether colored with Sudan III, for 10 minutes. Examination showed 7 with no ether in the tracheae and 5 which had ether in several tracheae but none with ether in all the tracheae.

Exp. 26. Four lice dipped in a light lubricating oil stained with Sudan III. Removed after 15 minutes, but no stain could be detected in the tracheae.

Most of the lice in these experiments were dead when removed from the liquid having been killed by the chemical passing directly through the body-wall, since no stain could be detected in the alimentary canal or in the tracheal system. Landois[20] has figured the closing apparatus of the pubic louse, which is similar to that of the clothes louse, and from the above experiments, the conclusion is reached that the louse is able to close this apparatus very quickly, but occasionally, as in the case of ether, a few tracheae are not closed quickly enough to keep out the chemical. A few experiments showed that the tracheae of the dog flea (*Pulex serraticeps*) were filled with stained ether after 1 minute immersion, but that the hog louse (*Haematopinus suis*) and the dog louse (*Haematopinus piliferus*) were somewhat resistant to its penetration, but not nearly so successful as the clothes louse. It is hoped to investigate this interesting observation more fully at some later date.

[20] Untersuchungen über die auf dem Menschen schmarotzenden Pediculinen. *Zeitschr. für wiss. Zool.* 15:494-503. 1865.

Two possible methods of killing the active stages are suggested by these results: first the addition to the washing suds of a chemical capable of penetrating the chitin of the body-wall during the period of washing, and toxic enough to produce its death, and second, the elevation of the temperature of the washing suds sufficiently high to destroy the lice. In general, a chemical capable of penetrating the body-wall during the period of washing would have to be rather volatile and hence not suitable for the work. Judging from published accounts, soaking garments in a bath containing cresol or lysol is practiced to a large extent in Europe.

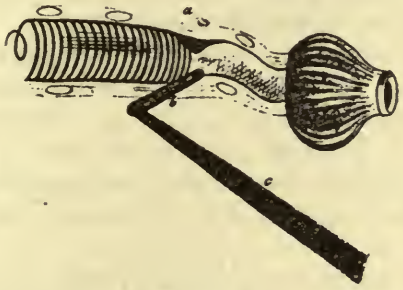


Figure 1
Sketch showing the closing apparatus in the trachea of the pubic louse (after Landois)

The garments, however, are not rinsed following their dip. Peacock[21] found a 1½ per cent cold cresol solution to be capable of destroying the lice and nits soaked in it for one hour. Nuttall[22] found a 5 per cent cresol and soap solution to kill lice and nits in 30 minutes, while a 2 per cent lysol solution at 76° F. (24° C.) killed the eggs after 5 minutes exposure. Bacot and Lloyd[23] consider that "the evidence as a whole seems to establish the fact that steeping for twenty minutes in a 2 per cent solution, either lysol or the cresol soap, is quite effective provided the temperature is not below 50° F." The following experiments were conducted to determine the efficacy of cresol either as a dip preceding washing, or when used in the wash suds.

Exp. 27. Dipped 12 recently fed lice in suds with 1 per cent tricresol added. Temperature 75° F. (24° C.). Transferred after 5 minutes to suds at 110°–114° F. (43°–45° C.) for 15 minutes rinsing in water at 112° F. (44° C.) for 3 minutes. Dried on filter paper when 10 lice revived.

Exp. 28. Same as Exp. 27 but cresol suds at temperature of 110°–114° F. (43–45°C.). 9 lice revived out of 16 used in the experiment.

[21] The Louse Problem at the Western Front. *Brit. Med. Journ.* 2:745-49; 784-88. 1916.

[22] Combating Lousiness among Soldiers and Civilians.

[23] Destruction of Nits of the Clothes Louse by Solutions of Cresol-Soap Emulsion and Lysol. *Brit. Med. Journ.* 1:479-80. 1918.

Exp. 29. Dipped recently fed lice in 1 per cent tricresol in ivory soap suds at 110°–114° F. (43°–45° C.) for 15 minutes, rinsing in water at 112° F. (44° C.) for 3 minutes. Dried, when 1 revived out of 17 lice.

Exp. 30. Dipped in 2 per cent tricresol in suds at 110°–114° F. (43°–45° C.) for 5 minutes. Placed in regular suds at 110°–114° F. (43°–45° C.) for 15 minutes rinsing in water at 112° F. (44° C.). Dried, no lice revived.

Exp. 31. Same as Exp. 30 but with 3 per cent tricresol. All lice killed by the treatment.

From these results, it is apparent that 2 per cent crude tricresol may be added to the washing suds or used as a dip preceding washing and prove effective in the destruction of the lice in the active stages. Altho the pieces of cloth were rinsed after treatment, an odor of cresol persisted, apparently being rather difficult to remove.

Bacot and Lloyd[24] point out that cresol emulsions are liable to decrease in insecticidal value in the presence of organic impurities. To what extent this action takes place is not known and it may vary greatly. Such being the case, and in view of the increased cost of using a chemical to destroy the lice, further experiments were made to determine to what extent heat might be used. A summary of these experiments follows. (Table IV.)

TABLE IV

SUMMARY OF 30-MINUTE TREATMENTS

			Dead	Revived
108°	−110°	avr. 108.8° F.(42.6° C.)	1	7
110°	−113°	avr. 110.7° F.(43.7° C.)	3	7
110°	−115°	avr. 111.6° F.(44.2° C.)	1	16
109°	−115°	avr. 112.4° F.(44.6° C.)	15	1
110°	−115°	avr. 113° F.(45° C.)	18	0
112°	−114°	avr. 113° F.(45° C.)	15	0

SUMMARY OF 22-MINUTE TREATMENTS

110°	−116°	avr. 112.8° F.(44.8° C.)	10	0
113°	−115°	avr. 114.2° F.(45.6° C.)	10	0
114°	−117°	avr. 115.2° F.(46.2° C.)	8	0

SUMMARY OF 15-MINUTE TREATMENTS

111°	−115°	avr. 112.3° F.(44.6° C.)	6	8
111°	−115°	avr. 113° F.(45° C.)	11	0
111°	−115°	avr. 113.3° F.(45° C.)	9	9
112°	−116°	avr. 114° F.(45.5° C.)	10	2
112.5°	−116°	avr. 114.2° F.(45.6° C.)	18	0
113.5°	−117.5°	avr. 114.9° F.(46° C.)	8	0
115.5°	−117.5°	avr. 116.5° F.(46.9° C.)	6	0

These experiments show the lethal temperature for lice is about 113° F. (45° C.) for 22- to 30-minute washings and a slightly higher temperature, 114.5° F. (45.8° C.) proved effective in 15 minutes' time. When woolen garments are quite soiled, the usual practice in laundries is to wash them at the higher temperature of 120°–125° F. (48°–52° C.), care being taken throughout the process to keep the temperature constant which is the important point in washing woolens to prevent shrinkage. These temperatures may be easily maintained in the washing-machine.

[24] Destruction of Nits of the Clothes Louse by Solutions of Cresol-Soap Emulsion and Lysol.

Considering the data presented, the following procedure is recommended for the laundering of woolen goods to destroy both lice and eggs. Infested garments may be washed at a temperature of 120° F. (49° C.), not to fall below 115° F. (46° C.) during the washing period of 15 minutes, this treatment destroying the active stages without the use of any special chemicals. Garments are then treated in the regular manner until perfectly dry, when they should be placed in the hot air tumbler at a temperature of 150°–170° F. (66°–77° C.) for 10 to 15 minutes. This destroys the eggs. By this method, it will be possible to launder woolens without shrinkage, and to destroy the lice and eggs without the use of a special chemical.[25]

These experiments have been corroborated in general by the experiments conducted in the regular army laundering units by Pierce, Moscowitz, and Hutchinson.[26] In their experiments the woolens were washed at a slightly higher temperature, 131° F., and dried in a hot air tumbler without shrinkage resulting.

Effect of heat on woolens.—Pierce and Moscowitz[26] found that shrinkage of woolens took place when heated dry in the tumbler, but did not when the woolens were dried in the tumbler. Woolman and McGowan[27] state that "certain influences increase the felting action, e.g., expansion due to heat, followed by sudden contraction from cold—changing from hot to cold water, or hanging the warm, wet fabric outdoors on a cold day." Fulton and Staniford[28] have shown that in the steam sterilization of woolen blankets, sudden opening of the sterilizer will cause shrinkage, while if only partly opened, allowing a gradual cooling, shrinkage does not result. It would appear, therefore, that if the dry woolens were heated in the hot air tumbler, avoiding too sudden changes in temperature, shrinkage would not result.

Matthews[29] states that in heating wool with water under pressure, the fibre is disorganized, due to the hydrolysis of the wool protein. It is to be expected that steam sterilization would produce such results and that repeated sterilizations would materially reduce the strength of the fabric.

[25] Pierce, Hutchison, and Moscowitz in an article appearing in the *National Laundry Journal* 81: no. 1, January 1919, state that I recommend washing woolens at a temperature of 123° F., preferably 125° F. to destroy the *eggs* of the lice. In the report to which they refer the following statement occurs: "Infested garments to be washed at a temperature of 120° F. not to fall below 115° F. during the washing period of fifteen minutes, this treatment to destroy the active stages without the use of any special chemicals. Garments are then treated in the regular manner until perfectly dry when they should be placed in the tumbler for a period of ten to fifteen minutes resulting in the destruction of the eggs."

W. M.

[26] MS reports to the Surgeon-General's office. August and September, 1918.

[27] Flowers of Sulphur and Lice. *Brit. Med. Journ.* 1:395. 1915.

[28] The Sterilization of Woolen Blankets and Uniforms. *Journ. Amer. Med. Assn.* 71: 823-24. 1918.

[29] The Textile Fibers, Their Physical, Microscopical and Chemical Properties. New York: John Wiley & Sons. 1913.

Presence of an alkali greatly increases the hydrolysis of the wool; hence drying garments in a hot air tumbler, if any alkali were present from the wash water, should produce similar results. The whole question of the effect of dry heat and of steam upon woolens is in need of further investigations before being adopted upon a larger scale.

FUMIGATION

The use of steam or hot air for the sterilization of the garments is superior to the use of a chemical for fumigation purposes, but in many cases, owing to the lack of proper facilities or fuel for carrying out such sterilization, a method of thoroly fumigating garments is necessary. To meet this need, carbon bisulphide,[30] carbon tetrachloride,[31] naphthalene,[32] creolin,[33] sulphur dioxide,[34] hydrocyanic acid,[35] and other chemicals have been considered. The small amount of vapor of the less volatile of these chemicals present in a saturated atmosphere at room temperature makes necessary a considerable degree of heat, or an exposure for a long period of time, to produce the desired results. The more volatile chemicals such as carbon bisulphide or carbon tetrachloride have so low a toxicity that unless large quantities of the chemical are used or the temperature is raised to the boiling point of the chemical, the insects are only stupified and soon revive. The slow penetration of hydrocyanic acid together with the difficulties of generating the gas restricts its use. Similar objections, to which may be added a relatively low toxicity, may be raised to sulphur dioxide.

In a study of the toxicity of a large number of chemicals[36] it was found that chlorpicrin, or nitrochloroform ($CCl_3\ NO_2$), altho quite volatile, possesses a very high toxicity. This high toxicity is due, in a large measure, to the ability of the chitin to absorb from the air even minute quantities of the chemical and to permit it to pass through into the insect's body.[37] In studies dealing with the fumigation of grain and flour, chlorpicrin showed

[30] Beitrage zur Bekämpfung der Kleiderläuse in Kleidern. *Centralbl. f. Bakt. u. Parasitenk.* 1 Abt. Orig. vol. 77:320-38. 1916.

[31] Entläusung mit Tetrachlorkohlenstoffgas. *Münchener med. Wochenschr.* 65:235-37. 1918.

[32] Nuovo metodo di sterilizzazione entom-parassitario. *Ann. d'Igiene.* 26:493-508. 1916. Abstract. *Review of Appl. Entom.* (series B) 4:177-78.

[33] I pidocchi ed i mezzi per distruggerli. *Ann. d'Igiene.* 26:92-108. 1916. Abstract, *Review of Appl. Entom.* (series B) 4:83. Muto, *op. cit.*

[34] Friedmann, *op. cit.*

[35] Insecticidal Fumigation in Ships with Special Reference to the Use of Hydrocyanic Acid and to the Prevention of Ship-Borne Yellow Fever. *Med Journ. of Australia* Nov. 4, 1916.
Entläusung durch Zyanwasserstoff. *Deutsch. med. Wochenschr.* 43:303-4. 1917.

[36] Volatility of Organic Compounds as an Index of the Toxicity of Their Vapors to Insects. *Journ. of Agric. Research* 10:365-71. 1917.

[37] Physical Properties Governing the Efficacy of Contact Insecticides.

great penetration.[38] Experiments were therefore conducted to determine its value in the fumigation of clothing to destroy lice and their eggs. Inasmuch as under field conditions only the simplest apparatus is available for the work, the fumigations were carried out in an ordinary galvanized iron ash can, without special efforts to make it air tight. Chlorpicrin of the desired quantity was poured upon the garments, while they were being packed in the can, thus insuring a more rapid evaporation and penetration. The results of these experiments (Table V) show that to evaporate the chlorpicrin rapidly in order that it may penetrate all parts of the clothing and destroy the eggs of the lice within 30 minutes, a small amount of heat is necessary. Three one-liter flasks filled with water heated to 80°–85° C. were found to answer the purpose. In practice the box might be heated to 30°–35° C. or hot stones might be used in the same manner as the flasks. Where no heat was available, a longer exposure is necessary. The active stages are more easily destroyed than eggs; hence in only two experiments were active stages used. They were placed in vials closed with gauze and the vials placed in pockets of the trousers in folds of the cloth, and in one case wrapped in 3 thicknesses of heavy underwear and placed in a leather ax case which was then strapped shut. The lice were used in experiments F and C and were in all cases killed.

Inasmuch as chlorpicrin is used in gas warfare, a supply should be available on the fighting front. Owing to its poisonous nature, and its irritating effect on the eyes, nose, and throat, it would be necessary for the operator to use a gas mask. Airing the clothing in the open for 3 to 5 minutes is sufficient to remove the chlorpicrin, after which the clothing can be worn.

No bleaching or fading of colored fabrics was observed in a number of tests made with fabrics of delicate coloring, providing the chlorpicrin contained no impurities of chlorine or nitrogen peroxide.[39] No injurious effect on leather was observed, but rubber is injured somewhat, altho not as much as might be expected.

The use of chlorpicrin is recommended as a means of delousing garments under conditions prohibiting the use of hot air or steam, since no particular apparatus is needed for the work. Chlorpicrin is superior to other chemicals recommended for fumigation since, on account of its extreme toxicity, high volatility, and ability to penetrate through masses of clothing, a high temperature is not necessary to insure the destruction of both eggs and active stages of the lice in a short period of time.

[38] Fumigation with Chlorpicrin. *Journ. of Econ. Ento.* 11:357-62. 1918.

[39] *Ibid.*

TABLE V

FUMIGATIONS WITH CHLORPICRIN

Treatment	Location of eggs in clothing	Age in days of eggs at time of fumigation	No. of eggs	Per cent hatched
A-6 c.c. of chlorpicrin in fumigation box of 2.5 cu. ft. for 20 minutes	Under seam of trouser leg	13	6	0
	Watch pocket of trousers	12	6	0
	In a fold of trousers	11	6	33.3
	Folded in bottom of cotton shirt	10	6	16.6
	Under collar of cotton shirt	9	7	100
	Pinned to front of flannel shirt	8	11	100
	Under neck of shirt	7	7	55.7
	Wrapped in piece of underwear in pocket of coat	6	8	75
	In pocket of heavy overcoat	5	11	27.2
	In pocket of heavy overcoat	4	2	100
	Wrapped in piece of underwear placed in leather ax case	3	7	28.6
	Rolled in sleeve of undershirt	2	7	57.1
	In cuff of flannel sleeve then rolled up	1	6	16.6
	In pocket of cotton shirt	½	8	37.5
B-10 c.c. of chlorpicrin to 2.5 cu. ft. for 30 minutes	Wrapped in underwear and placed in leather ax case	13	6	33.3
	Pocket of trousers	12	6	0
	Underwear pocket folded 3 times	11	5	0
	Bottom seam of cotton trousers rolled over 3 times	10	5	0
	Collar of cotton coat	9	7	42.8
	Pinned to front of undershirt	8	12	33.3
	Seam of khaki trousers	6	7	37.5
	Underneath collar of flannel shirt	6	7	42.8
	Cuff of flannel shirt sleeve rolled up	5	7	28.5
	Pocket of coat	4	6	0
	Pocket of overalls	3	7	55.7
	Pocket of heavy overcoat	2	8	0
	Sleeve of undershirt	1	7	0
	Under collar of cotton overalls	½	6	0
C-10 c.c. of chlorpicrin to 2.5 cu. ft. for 10 minutes	Wrapped in underwear placed in pocket of overalls	13	6	0
	Seam at bottom of overall. Leg rolled up	12	6	0
	Waist band of overalls	11	5	0
	Under collar of flannel shirt	10	5	0
	Rolled in sleeve of shirt	9	7	55.7
	In fold of khaki trousers	8	10	30

TABLE V—*Continued*

FUMIGATIONS WITH CHLORPICRIN

REATMENT	LOCATION OF EGGS IN CLOTHING	AGE IN DAYS OF EGGS AT TIME OF FUMIGATION	NO. OF EGGS	PER CENT HATCHED
	Pinned to front of flannel shirt	7	10	80
	Wrapped in underwear placed in pocket of shirt	5	6	16.6
	Bottom seam of khaki trousers	6	9	11.1
	Pinned to bottom of coat	4	7	0
	Placed in overall pocket	3	9	0
	Placed in leather ax case	2	8	0
	Placed in pocket of cotton shirt	1	6	33.3
	Pinned to back of cotton shirt	½	6	0
D-control for A, B, and C		13	5	20
		12	7	14.3
		10	1	100
		9	50	84
		8	36	75
		7	15	40
		6	4	0
		5	5	40
		4	8	0
		3	6	16.6
		2	6	0
		1	7	0
		½	8	0
E-10 c.c. of chlorpicrin to 2.5 cu. ft. for 15 minutes. Heated by placing in box 3 1-liter flasks filled with water at 80° C.	Under collar of coat	12	7	0
	In leather ax case	11	5	0
	Wrapped in cloth in pocket of khaki trousers	10	6	0
	Under collar of shirt	9	6	0
	Under front seam of trousers	8	5	0
	In fold of trouser leg	7	5	0
	Wrapped in a piece of underwear placed in shirt pocket	6	4	0
	Placed in pocket of heavy overcoat	5	3	0
	Wrapped in an undershirt	4	6	0
	Pinned to gray flannel shirt	3	4	0
	Attached to sleeve of gray shirt. Rolled up 6 folds	2	6	16.6
	Pocket of gray coat	1	6	0

TABLE V—*Continued*

FUMIGATIONS WITH CHLORPICRIN

Treatment	Location of eggs in clothing	Age in days of eggs at time of fumigation	No. of eggs	Per cent hatched
	Pinned in fold of khaki trousers	½	6	0
F-10 c.c. of chlorpicrin to 2.5 cu. ft. for 30 minutes	Pocket of gray coat	13	6	0
	Wrapped in cloth in pocket of khaki trousers	12	6	0
Heated by 3 1-liter flasks filled with water at 82° C.	Under collar of gray shirt	10	6	0
	In pocket of heavy overcoat	9	6	0
	Sleeve of flannel shirt rolled up 6 folds	8	4	0
	In fold of undershirt	5	6	0
	Under collar of gray flannel shirt	3	6	0
	Rolled up in leg of cotton trousers	2	4	0
	Attached to seam of cotton trousers	1	6	0
	Pinned to gray flannel shirt	½	6	0
G-10 c.c. of chlorpicrin to 2.5 cu. ft. for 15 minutes. Heated with 3 1-liter flasks filled with water at 80° C.	Pocket of khaki overalls	13	8	0
	Pocket of gray coat	12	7	0
	Wrapped in cheesecloth pinned under arm of flannel shirt	11	6	0
	Pinned to front of undershirt	10	2	0
	Pinned to shoulder seam of flannel shirt	9	5	20
	Under collar of cotton shirt	5	6	0
	In pocket of heavy cotton shirt	3	6	0
	Under leg seam of khaki overalls	1	6	0
	In watch pocket of cotton trousers	½	6	0
H-control for E, F, and G		13	4	0
		12	5	40
		11	8	0
		10	6	16.6
		9	6	0
		8	7	0
		7	5	0
		6	3	0
		5	6	0
		4	6	0
		3	6	50

TABLE V—*Continued*

FUMIGATIONS WITH CHLORPICRIN

Treatment	Location of eggs in clothing	Age in days of eggs at time of fumigation	No. of eggs	Per cent hatched
H-control for E, F, and G		2	6	0
		1	6	66.7
		½	6	0
I-10 c.c. of chlorpicrin to 2.5 cu. ft. for 30 minutes Heated by 3 1-liter flasks of water at 80° C.	Rolled up in sleeve of woolen jacket 6 folds	14	7	0
	Under arm seam of woolen jacket	13	10	0
	Under fold of cotton shirt	12	10	0
	Under collar of heavy cotton shirt	11	9	0
	In watch pocket of khaki overalls	10	10	0
	In thick fold of leg of khaki overalls	9	9	0
	In pocket of heavy cotton trousers	8	10	0
	Under leg seam of cotton trousers	7	10	0
	Pinned to front of undershirt	6	10	0
	Inside sleeve of undershirt	5	10	0
	Under arm seam of cotton coat	4	10	0
	Under sleeve seam of cotton coat	3	10	0
	Pocket of cotton coat	2	10	0
	Under collar of gray flannel shirt	1	10	0
	Folded in cuff of gray flannel shirt	½	10	0
J-control for I		14	6	0
		13	10	10
		12	10	10
		11	10	50
		10	10	10
		9	10	10
		8	10	10
		7	10	60
		6	10	80
		5	10	20
		4	10	30
		3	10	30
		2	10	30
		1	10	10
		½	10	20

TABLE V—*Continued*

FUMIGATIONS WITH CHLORPICRIN

Treatment	Location of eggs in clothing	Age in days of eggs at time of fumigation	No. of eggs	Per cent hatched
K-10 c.c. of chlorpicrin to 2.5 cu. ft. for 20 minutes 3 1-liter flasks of water at 80° C. used to heat fumigation box	Pinned along seam of brown trousers	17	7	0
	In triple fold of brown cotton trousers	14	9	0
	Pinned at waist of brown cotton trousers	13	7	0
	Pinned in double fold of cotton trousers	13	8	0
	Rolled 4 folds in undershirt	12	8	25
	Pinned to edge of undershirt	12	7	14.3
	Pinned to front of undershirt	11	11	18.1
	Folded under collar of undershirt	11	10	0
	Folded under 6 folds of collar of flannel shirt	10	9	33.3
	Pinned to collar of flannel shirt	10	8	25
	Pinned in 5 thicknesses of woolen cloth	9	11	27.2
	Pinned to outside of woolen cloth	9	10	20
	Attached to cuff of cotton coat rolled 16 times	8	10	0
	Attached to cuff of cotton coat rolled 6 times	8	9	0
	Attached to outside of cotton coat	8	10	0
	Attached to cuff of light cotton coat. Rolled 13 times	7	8	0
	Attached to outside of above roll	7	7	0
	Attached to cuff of flannel coat tightly rolled 20 times	6	10	0
	Attached to cuff of flannel coat tightly rolled 8 times	6	10	0
	Attached to outside of flannel coat tightly rolled	6	8	12.5
	Bottom of khaki overalls. Tightly rolled 12 times	5	11	9
	Bottom of khaki overalls. Tightly rolled 6 times	5	10	10
	Outside of khaki overall roll	5	13	7.7
	Inside of cotton pad rolled 3 times	4	11	17.2
	Outside of cotton pad	4	11	0
	Pinned to back of cotton collar	3	3	33.3
	Pocket of cotton coat	2	7	0
	Pocket of khaki overalls	1	12	25
	Pinned to front of cotton shirt	½	9	0

TABLE V—*Continued*

FUMIGATIONS WITH CHLORPICRIN

Treatment	Location of eggs in clothing	Age in days of eggs at time of fumigation	No. of eggs	Per cent hatched
L-control for K		17	7	0
		14	4	50
		13	17	47
		12	15	40
		11	22	27.2
		10	17	17.7
		9	19	16
		8	27	22.2
		7	18	22.2
		6	25	4
		5	36	30.5
		4	21	33.3
		3	2	100
		2	7	57.1
		1	11	27.2
		½	8	50

METHODS OF LOUSE DESTRUCTION BY PEDICULICIDES

Even tho the methods of freeing the soldiers' clothing of lice should be perfect, in practice it is impossible to carry out such measures with more than a limited number of men in one day. Further, it appears to be impossible to segregate the clean men until such time as their comrades have been cleaned. Such being the case, the soldier comes in contact with lousy men and becomes reinfested, not once but possibly many times in the period between lousings. It is for this reason that the need of a good pediculicide arose, and it is possible that, due to the lack of such a pediculicide, the louse problem reached the magnitude it has in the present war. To supply this need large numbers of chemicals have been experimented with and recommended for use. Hase[40] mentions as many as 181 in his experiments, while Nuttall[41] lists 110 that have been recommended in practice. The motto in the work appears to be "try everything" and this has been done without an effort being made to determine any of the principles which may govern the action of the chemicals. The present investigation was conducted primarily to ascertain first, the principle upon which the insecticide acts, and second, by the application of this principle, to produce better preparations. Many chemicals have been used, not with the idea of their value as pediculicides, but rather to elucidate the action of chemicals used in that manner. Throughout the work certain principles governing the toxicity of volatile organic compounds have been used which were discovered previous to this investigation.[42] These principles may be briefly outlined as follows:

1. The volatility, of which the boiling point is in general an index, influences to a marked extent the toxicity of the vapor of the chemical.
2. The lower the boiling point of a chemical the greater is the quantity of the chemical which may be held by a given quantity of air.
3. Using a saturated atmosphere of the vapor of a chemical, it was found that death was produced most quickly by the chemical with the lowest boiling point (highest volatility), while compounds with very high boiling points required long periods of time to produce death.
4. Using equal quantities of the vapor, death is produced most quickly by the compound with the highest boiling point (lowest volatility).

An example of the manner in which these principles work may make the meaning clearer. A saturated atmosphere of benzene (b.p. 80.36° C.) containing about .184 grams per liter of air will kill house flies in about 13 to 15 minutes at a temperature of 20°–22° C. while a saturated atmosphere of nitrobenzene (b.p. 205° C.), which contains only about .004 grams

[40] Weitere Beobachtungen über die Läuseplage. *Centralbl. f. Bakt. u. Parisitenk.* 1 Abt. Orig. vol. 77: 153-63. 1915.

[41] Combating Lousiness among Soldiers and Civilians.

[42] Volatility of Organic Compounds as an Index of the Toxicity of Their Vapors to Insects. Physical Properties Governing the Efficacy of Contact Insecticides.

per liter, requires 115 minutes. On the other hand, using equal quantities of the vapor it is found that .004 grams of benzene act so slowly that more than 7 hours are required to produce death. This period is so long that death may not be entirely due to the action of the benzene vapor. Naturally, chemical activity has a bearing upon its toxicity, but in general, unless the chemicals have nearly the same volatility, the difference in chemical activity is entirely masked by the changes in toxicity due to changes in volatility.

An examination of the louse problem shows four different methods by which a pediculicide may be applied; first, direct contact of the chemical; second, sachets; third, louse powders; fourth, impregnation of the underwear.

Direct Contact of the Chemical

Many different chemicals have been recommended to be rubbed along the seams of the clothing to destroy lice and their eggs. Some of these compounds are for the purpose of killing by direct contact, while others are thought to act as repellants. Almost any active liquid chemical with a boiling point above 160° C. and below 250° C. will destroy lice and their eggs when brought into direct contact with them; hence no special investigation of this phase of the problem was made. Cresol or lysol are possibly the cheapest of the chemicals which might be used for this purpose. Inasmuch as all the lice and nits would not be reached by this method, and since it would not protect from reinfestation, it can not be recommended as an effective method of louse control.

Concerning the use of repellants, observations with many chemicals throughout the experiments show that those compounds which acted as repellants were actual poisons, present in too small quantities actually to kill the lice, or very slow in action, due to a very low volatility. It appears very doubtful if a compound repellant to lice exists which, under more favorable conditions, would not actually kill them.

Use of Sachets

Primitive man protected himself from different ills and evil influences by wearing a charm suspended from the neck, while modern man continuing the same method, has substituted a bag of asafoetida or camphor for the charm. Such is probably the origin of the sachet method of protecting the soldier from attacks of lice. Naphthalene,[43] camphor,[44] sulphur,[45] paradichlorbenzene,[46] and various other chemicals[47] have been used in sachets

[43] Zur Prophylaxe des Flecktyphus. *Deutsch. med. Wochenschr.* 41:12. 1915.

[44] Mesures prophylactiques contre le typus exanthématique et le typus récurrent. *Paris Med.* 5:206-12. 1915. Abstract, *Review of Appl. Entom.* (series B) 3:232.

[45] Shipley, *op. cit.*

[46] Hase, *op. cit.*

[47] Control of Lice in the Active Army. *Proc. Confer. Bacter. Moscow* pp. 70-71. 1915. Abstract, *Review Appl. Entom.* (series B) 3:122-23.

worn suspended from the neck or from the waist of the soldier. Inasmuch as these chemicals give off a vapor which is toxic to insects, it was thought that this method might be of some value in the destruction of the lice. In the preliminary experiments, muslin bags containing 5 to 10 grams of the chemical to be tested were suspended from the neck while a wide-mouthed vial containing the lice was fastened at the waist line. The opening of the vial was closed by means of a piece of bolting cloth, to prevent the escape of the lice. Naphthalene, paradichlorbenzene, and chloretone were used in these experiments, but the lice were not only active but even laid eggs during the exposure. One experiment in which naphthalene was used, had the bag located not more than 5 or 6 inches from the vial. The subject slept, covered with a heavy woolen blanket in addition to the normal clothing, and after an interval of several hours the lice were found to be dead.

From results of previous experiments with insects, even small quantities of these chemicals having rather high boiling points should prove toxic to the lice. Two explanations are possible to account for their failure; either the diffusion of the vapor was so slow that it failed to reach the lice in sufficient quantity to prove fatal, or the rate at which the chemical escaped from the space between the body and the clothing was so rapid compared with the rate at which it evaporated, that not sufficient vapor was retained under the clothing to bring about the death of the lice. In large glass cylinders where there is no opportunity of escape, the vapor diffuses sufficiently in a few hours to kill lice in all parts of the vessel. It appears, therefore, that the ineffectiveness of these compounds must be due to the rapidity with which their vapors escape from the clothing. The following experiments were conducted to determine the accuracy of this point.

Five-gram lots of the compounds to be tested were weighed out in watch glasses and placed in wide-mouthed jars lying on their sides. The openings of the jars were covered with different types of cotton, wool, and silk underwear, woolen and khaki clothes, and combinations of these to as many as three or four thicknesses. Our control jar was left open, while another was closed with a glass top. From a comparison of the amount of evaporation from these jars, it is possible to arrive at an estimation of the amount of diffusion through the different types of clothing. In the case of the jar closed with a glass top, the air soon became saturated with the vapor after which no further evaporation occurred. This amount was so small in the case of camphor, naphthalene, and paradichlorbenzene, that no difference in weight could be detected in the compound. The loss in weight due to evaporation from the open jar was considered as representing the quantity of vapor, which escaped and was taken as 100 per cent. Upon this basis, it was found that the loss in weight of naphthalene contained in jars closed with different types of clothing varied from 44 per cent to 88 per cent, and paradichlorbenzene from 55 per cent to 62 per cent of

the loss in weight from the open jar. (Table VI.) These experiments were all conducted in a room heated to a temperature of 26°–28° C.

From these results, it is apparent that not more than 15 to 50 per cent of a saturated atmosphere of these chemicals could be retained under the soldiers' uniform. In actual practice, the percentage is much less, due to the escape of the vapor through openings about the neck, arms, etc., the diffusion being increased by movements of the diaphragm.

TABLE VI

EVAPORATION OF VOLATILE COMPOUNDS FROM JARS CLOSED WITH DIFFERENT KINDS OF CLOTH

NAPHTHALENE

	Per cent
Check	100
Light cotton gauze underwear	66
Medium cotton and wool underwear	88
Medium cotton underwear	66
Medium silk and cotton underwear	66
Medium silk underwear	88
Heavy cotton fleece-lined underwear	88
Heavy cotton and wool underwear	85
Blue flannel	77
Double blue flannel	44
Muslin underwear, woolen shirt, khaki coat	50

PARADICHLORBENZENE

	Per cent
Check	100
Medium wool and cotton underwear	62
Fleece-lined cotton underwear	55
Light cotton gauze underwear	60

XYLENE

	Per cent
Check	100
Fleece-lined cotton underwear	46
Light gauze cotton underwear	50
Medium silk underwear	50
Medium wool and cotton underwear	42
Heavy cotton underwear	46
Muslin underwear, woolen shirt, khaki coat	43

Such low percentages of saturation are not sufficiently high in the cases of naphthalene, paradichlorbenzene, camphor, etc., to result in effective control of the lice. Bacot[48] obtained similar results, but considered them to be due to the slow diffusion of the chemicals tested.

Better results might be obtained by selecting such chemicals as have a rate of evaporation high enough to overcome in a large measure the loss due to leakage through the clothing. Similar experiments were therefore conducted with xylene mixed with fuller's earth. The leakage amounted to from 40 per cent to 45 per cent, while 50 per cent of a saturated atmosphere of xylene is sufficient to produce death. Bags of fuller's earth containing xylene, worn about the neck, killed lice contained in a vial suspended at the waist line, but the xylene in contact with the skin burned

[48] The Use of Insecticides against Lice. *Brit. Med. Journ.* 2:447-50. 1916.

and produced blisters. This objection was overcome by preventing the bag from coming in contact with the skin by means of a piece of tin foil or rubber sheeting.

An opportunity of determining the value of this method presented itself when a student was found infested with the pubic louse. He consented to give the sachet method a trial under conditions similar to those encountered in the field. Two bags containing fuller's earth and xylene were attached to a tape tied around the body about 3 inches above the waist line. Within 6 hours all the lice were stupified and fell down his trouser legs, lodging in his underwear below the knees. In this position there was insufficient vapor of xylene to bring about death, and in a few hours the lice revived, attaching themselves to the hairs of his leg in the form of a circle. Other means were then taken to free him of these objectionable insects.

From these experiments it is apparent that sachets of naphthalene, camphor, paradichlorbenzene, or other high boiling point compounds would not be successful in practice, since the leakage through the clothing is too rapid in comparison with their rate of evaporation. Chemicals with lower boiling points, such as xylene, will evaporate rapidly enough to maintain a quantity of vapor under the clothing sufficient to produce the death of the lice. Owing to the fact that the lice are first stupified, and fall into a region where the vapor is absent or not present in sufficient quantity to produce death, it would be necessary to attach one or more sachets on each leg. Considering the large quantity of xylene evaporating each day from one sachet, and adding to this the large number of sachets which would have to be worn to prove effective, it is at once apparent that the expense makes protection by means of sachets impossible.

In order that a chemical with a high boiling point may be used successfully as a pediculicide, its evaporation must be increased by exposing a large surface of the chemical. This may be accomplished in two ways, either in the form of a powder dusted through the clothing or by the direct impregnation of the underwear. Either method further increases the action of the chemical by bringing it into direct contact with the louse.

Louse Powders

Powders have been used extensively in the control of parasitic insects on domesticated animals, and it is natural that similar powders should be recommended for the destruction of clothes lice. Pyrethreum powder has been extensively used as a louse powder, or as the chief ingredient of the louse powders. Pyrethreum, altho it will destroy lice in contact with it for a long period, usually first stupified the lice, causing them to fall out of the active zone of the powder. Naphthalene has been used as a louse powder with more or less success, but the most successful powder has

been the N. C. I. powder[49] made of naphthalene, 96 per cent, creosote, 2 per cent, iodoform 2 per cent.

The N. C. I. powder.—Altho N. C. I. has proved most successful, several objections have been offered to this preparation; first, that it is moist, and hence difficult to dust through the clothing, and second, it is inclined to burn the skin, particularly in the fork of the legs. Preliminary experiments agreed with the results of Kinlock[50] that an atmosphere saturated with the vapor of the combined powder was more toxic than the vapor of any one of its constituents. The problem, therefore, was to determine the cause of this increased toxicity. It would appear that the creosote being more volatile than either naphthalene or iodoform would evaporate, leaving a powder composed of naphthalene and iodoform only. Observations have shown that when N. C. I. is exposed to the air for several days it becomes dry and is then of no more value as a louse powder than naphthalene itself. Naphthalene and iodoform being somewhat soluble in creosote, a saturated solution of both these chemicals was prepared. This solution proved as toxic as the N. C. I. powder. Inasmuch as the two grams of creosote present in 100 grams of N. C. I. would dissolve only about one third of a gram of naphthalene and about one twelfth of a gram of iodoform, there does not appear to be any reason why such large quantities of these chemicals should be used in the powder. After experiments with Lloyd's alkaloid reagent, fuller's earth, and a few other similar inert ingredients, talc was selected as a basis for the powder. Using talc, a larger quantity of creosote could be used and the finished product still remain dry in comparison with the moist N. C. I. The powder made of twenty grams of talc, one-half gram of naphthalene, one-half gram of iodoform and 1 c.c. of creosote was found to be just as effective as the N. C. I., with the added advantage of being drier and much cheaper. (Table VIII.) Experiments showed that the creosote alone was not as effective as when either naphthalene or iodoform was added, but creosote naphthalene, or creosote iodoform, appeared to be slightly better than a combination of all three chemicals.

TABLE VII

VOLATILITY OF CERTAIN CHEMICALS USED IN LOUSE POWDERS

Compound	Grams per sq. cm. ½ hour
Creosote	.001312
Methyl salicylate	.002424
Naphthalene	.0008609
Iodoform	.0001716
Naphthalene in creosote 8 per cent solution	.001622
Naphthalene creosote 50–50	.001928
Iodoform in creosote saturated solution	.001202
Iodoform and naphthalene in creosote saturated solution	.001806
Sulphur in creosote saturated solution	.001323
Naphthalene in methyl salicylate	.003451

[49] Peacock, *op. cit.*

[50] An Investigation of the Best Methods of Destroying Lice and Other Body Vermin. *Brit. Med. Journ.* 1:789-93. 1916.

Principles of louse powders.—The value of the N. C. I. or a similar powder appears to be due to the less volatile and more toxic naphthalene and iodoform evaporating with the creosote, just as in fractional distillation the lower fraction of a liquid carries over small quantities of the higher boiling liquid. At the time that the powders listed in Table VIII were prepared and tested, this point could not be definitely determined, but after the apparatus for studying volatility, described later in this paper, was available, data were obtained. (Table VII.) From these results it is seen that the addition of naphthalene to creosote or methyl salicylate increases the loss in weight per half-hour. The loss is greater with methyl salicylate, possibly due to the greater solubility of naphthalene in it. The addition of iodoform slightly reduces the loss in weight while sulphur does not appear to affect it. By the evaporation of saturated solutions of naphthalene or iodoform in creosote to dryness at room temperature, it was found that the creosote carries the naphthalene or iodoform with it. When naphthalene and iodoform were both present to saturation in the creosote, crystals were found in the dish, as it approached dryness, showing that the creosote could not carry both as well as it could either one. From a mixture of .09 grams of sulphur with 7.7 grams of creosote, after evaporation, .0856 grams of sulphur were recovered. Considering the possibilities of the loss of particles of sulphur during its recovery, it is apparent that in evaporating, the creosote carries very little, if any, sulphur with it. A good louse powder would, from these studies, contain a liquid of about the volatility of creosote, in which was dissolved a more toxic and less volatile liquid or solid, to be carried to the insect by the vapor of the more volatile portion. These chemicals forming the active principle of the louse powder can then be mixed with an inert carrier such as talc, in order that the finished powder may be dry and easy to dust through the clothing.

Experiments with different powders.—Using this principle, it was found easy to make any number of powders equal or surpassing N. C. I. in toxicity. Pieces of underwear were dusted with the powder and laid over a small square of cloth to which the lice were attached. At the end of the period of time determined for the experiment, the underwear was removed and all particles of powder adhering to the lice removed as far as it was possible. The lice were then placed in a clean vial, and left for 12 to 24 hours in the incubator to determine the percentage actually killed. This precaution was necessary as lice are often stupified, possibly due to the closure of their spiracles in the presence of a toxic vapor, just as when they are dipped in soap solutions. An examination of the results show that methyl salicylate is not as good as creosote, possibly due to its greater volatility. Crude phenol or crude cresol would serve better as substitutes. Many of the toxic chemicals used would be too poisonous or too expensive for use on the body, but are listed to show the correctness of the principle

TABLE VIII

EXPERIMENTS WITH LOUSE POWDERS

Composition of powders	Per cent killed in minutes			
	5 min.	10 min.	20 min.	30 min.
N.C.I. (naphthalene 96 per cent, creosote 2 per cent, iodoform 2 per cent)	...	...	66	100
Talc 20 grams, naphthalene ½ gram, creosote 1 c.c. iodoform ½ gram	...	...	66	100
" 20 " creosote 1 c.c.	...	...	0	100
" 20 " creosote 1 c.c., naphthalene ½ gram	...	66	100	100
" 20 " creosote 1 c.c., iodoform ½ gram	...	0	100	100
" 20 " creosote ½ c.c., oil of sassafras ½ c.c.	...	...	...	0
" 20 " creosote ½ c.c., amyl alcohol ½ c.c.	...	...	0	100
" 20 " creosote ½ c.c., methyl salicylate ½ c.c.	...	...	0	100
" 20 " creosote ½ c.c., carbolineum ½ c.c.	...	...	0	0
" 20 " creosote ½ c.c., crude phenol ½ c.c.	66	100	100	100
" 20 " creosote 1 c.c., chloretone ½ gram	..	33	100	...
" 20 " methyl salicylate 1 c.c., chloretone ½ gram	...	...	0	...
" 20 " creosote 1 c.c., alpha-naphthylamine ½ gram	...	...	66	...
" 20 " methyl salicylate 1 c.c., alpha-naphthylamine ½ gram	...	...	33	...
" 20 " creosote 1 c.c., paranitrophenol ½ gram	...	33	100	...
" 20 " methyl salicylate 1 c.c., paranitrophenol ½ gram	...	...	66	...
" 20 " methyl salicylate 1 c.c., iodoform ½ gram	...	...	0	...
" 20 " methyl salicylate 1 c.c., naphthalene ½ gram	...	...	0	...
" 20 " methyl salicylate 1 c.c., quinone ½ gram	...	100	100	...
" 20 " methyl salicylate 1 c.c., paranitrobenzylchloride ½ gram	...	...	33	...
" 20 " creosote 1 c.c., ortho- and parachlornitro-benzene ½ gram	...	66	100	...
" 20 " creosote 1 c.c., picric acid ½ gram	...	...	0	...
" 20 " creosote 1 c.c., alphanaphthol ½ gram	...	66	100	...
" 20 " creosote 1 c.c., betanaphthol ½ gram	...	66	100	...
" 20 " creosote 1 c.c., paradibrombenzene ½ gram	66	100	100	...
" 20 " creosote 1 c.c., menthol ½ gram	...	...	66	...
" 20 " creosote 1 c.c., monochloracetic acid ½ gram	100	100	100	...
" 20 " creosote 1 c.c., chloranil ½ gram	...	...	0	...
" 20 " creosote 1 c.c., sulphur ½ gram	100	100	100	...
" 20 " creosote 1 c.c., cumarin ½ gram	...	66	100	...
" 20 " creosote 1 c.c., camphor ½ gram	0	100	100	...
" 20 " creosote 1 c.c., isoborneol ½ gram	66	100	100	...
" 20 " creosote 1 c.c., monobromated camphor ½ gram	66	100	100	...
" 20 " crude phenol 1 c.c., naphthalene ½ gram	...	0	...	...
" 20 " crude phenol ½ c.c., creosote ½ c.c., naphthalene ½ gram	...	66	...	...
" 20 " creosote 1 c.c., naphthalene and sulphur to saturation	33	100	...	...
" 20 " creosote 1 c.c., sulphur to saturation	66	100	...	...

upon which the powders were prepared. The chemicals which in the later studies proved best for the impregnation of the underwear could also be used in the manufacture of effective louse powders.

The results obtained with creosote and sulphur were surprising, since sulphur is not carried by the vapor of creosote. Considered from the standpoint of cheapness, results, and effect on the skin, talc 20 grams, creosote 1 c.c. and sulphur ½ gram formed the best louse powder. A number of experiments were tried with this powder, and, altho in some cases the lice when removed from the powder at the end of five minutes showed signs of life, in all cases they died within the next few hours. The experiments with creosote saturated with sulphur demonstrated that an excess of sulphur was necessary to give the best results. Sulphur alone dusted on underwear and covered over the lice for 5-, 10-, or 20-minute periods, failed in all cases to kill the lice, or even to stupify them. Sulphur has often been advised for use in destroying lice, but altho some results are favorable, others are just as unfavorable. It may be that when sulphur is brought into contact with the lice under the proper conditions it proves destructive, while if these conditions are not attained, unfavorable results are obtained. The creosote present in the powders may, by bringing the sulphur into close contact with the louse, produce conditions favorable to the effective action of the sulphur.

The sodium or calcium salt of cresol or a halogenated cresol, described in the section dealing with the impregnation of the underwear, might be used successfully as a louse powder. Particles of these chemicals remaining in the underwear would be gradually decomposed by the action of carbon dioxide and moisture given off by the body, forming the original cresol. Such a powder would be effective for a longer period than those previously mentioned.

The use of powders.—Two points may be mentioned concerning the use of powders to destroy lice. The soldier, in general, objects to their use since effective powders are inclined to produce irritation, particularly when the soldier is perspired, while powders which do not burn are of no value. The second point is the enormous quantity of powder necessary to treat effectively the great numbers of men at the front. Using two ounces of powder for one application, the quantity which would be necessary for good results, would mean 1,250 pounds to each ten thousand men. The action of the powder is such that few, if any, eggs of the lice would be destroyed; hence it would be necessary to repeat the treatment about every two days. The quantity of powder demanded for an army would be enormous, and when one considers that about 90 per cent of the powder is inert material, its use can not be recommended other than as a supplementary control measure for use under exceptional conditions.

Impregnation of the Underwear

Lobaczewski[51] used Ol. bettulae 30 per cent in 96 per cent alcohol to impregnate underwear, claiming that the effect was lasting. Bacot[52] used a mixture of equal quantities of crude carbolic acid and soft soap diluted with water to make a 5 to 10 per cent carbolic acid solution. Shirts impregnated with this chemical were effective for about a week. Gunn[53] used 10 per cent of naphthalene and 10 per cent sulphur dissolved in benzene or gasoline to impregnate cheese cloth garments, which were worn at the front and reported to be very effective. No definite experiments are given, and since naphthalene will evaporate from such a suit within 24 to 48 hours, and Bacot[54] has shown sulphur impregnations to be ineffective, it is doubtful if such suits are of any insecticidal value. Cytisine was experimented with by Bacot[55] but was discarded due to its high toxicity, being an alkaloid similar in physiological effects to nicotine. Nuttall[56] mentions experiments by Peacock with calcium monochlorcresol and copper monochlorcresol as being effective, but of no use when men are heavily infested.

Since impregnation appears to be the most efficient method of applying the insecticide, but a method which has not been extensively investigated, a long series of experiments was conducted to determine its possibilities.

The use of oils.—Hase[57] has shown that when the underwear is worn until it becomes dirty and greasy that few or no lice are found in it. In northern Minnesota some of the lumbermen also recognize this method of ridding themselves of lice. Whether this practice is of value due to the grease or oil present in the underwear proving objectionable to the lice or to the higher temperature under such underwear is not known, but it is interesting to know that in Africa many tribes of natives rub their bodies with oil or grease and such natives are usually comparatively free of lice. Due to these suggestive observations, in the first experiments, oils were used to impregnate underwear. The essential oils were not used since they depend for their effectiveness largely upon volatile fractions which soon disappear. Slightly volatile or non-volatile mineral, vegetable, and animal oils were used to saturate pieces of woolen underwear which were then cut into pieces about 1 cm. square and placed in small vials. Lice were then introduced and the vial placed in the incubator. The lice were fed twice a day, and as it was noted that in many cases the lice were inclined

[51] Zur Frage der "Entläusung." *Wien. klin. Wochenschr.* 28:373-74. 1915.

[52] The Use of Insecticides against Lice.

[53] A Note on the Prevention of Pediculosis. *Brit. Med. Journ.* 1:579-80. 1917.

[54] The Use of Insecticides against Lice.

[55] *Ibid.*

[56] Combating Lousiness among Soldiers and Civilians.

[57] Hase, *op. cit.*

TABLE IX

IMPREGNATION WITH OILS

Oils used in the experiments	No. of c.c. used to 1 sq. in.	Viscosity water = 1	No. of lice used in experiment	Percentage dead at different periods of time (hours)										No. of eggs laid	Per cent of eggs hatched
				12	24	36	48	60	72	84	96	108	120		
No. 2 EPMO	1	30	12	83	83	100	..	..	..	..	..	..	..	..	...
No. 3 EPMO	½	30	12	16	75	92	100	..	..	..	..	..	..	..	...
No. 4 EPMO	⅛	30	12	33	66	100	..	..	..	..	..	..	..	..	...
No. 5 EPMO	¼	30	12	16	41	58	83	92	92	92	100	..	..	13	100
No. 6 EPMO	⅛	30	12	0	0	0	0	8	8	16	25	41	41	83	72
No. 20 PPO	¼	14.1	9	0	55	55	55	77	88	88	100	..	..	0	...
No. 5 EPMO	¼	30	12	17	42	59	83	92	92	92	100	..	..	13	100
No. 21 WMO	¼	58.78	9	0	22	44	44	55	77	77	88	100	..	0	...
No. 26 PHM	¼	530.3	10	10	40	70	80	80	100	..	..	..	..	0	...
No. 25 Cylvalette	¼	2374.27	10	10	60	70	80	100	..	..	..	..	..	0	...
No. 27 Petrolatum	¼	.....	9	0	44	44	66	66	77	88	88	100	..	2	50
No. 15 Chlorocosane	¼	.....	10	0	0	0	0	0	10	10	20	20	20	22	100
No. 14 Chlorocosane	⅛	.....	11	0	10	10	10	10	10	10	30	30	50	8	87
No. 1 Vaseline and paraffine	..	.....	12	0	0	8	33	33	33	33	33	42	59	104	49
No. 84 Pa. crude oil	⅛	.....	10	0	40	60	60	60	100	..	..	..	..	0	...
No. 85 Pa. crude oil	⅛	.....	11	36	36	100	..	..	..	..	..	..	..	0	...

TABLE IX—*Continued*

IMPREGNATION WITH OILS

Oils used in the experiments	No. of c.c. used to 1 sq. in.	Viscosity water=1	No. of lice used in experiment	Percentage dead at different periods of time (hours) 12	24	36	48	60	72	84	96	108	120	No. of eggs laid	Per cent of eggs hatched
No. 158 Kansas crude oil	1/8	.....	10	0	30	80	80	80	80	80	80	80	80	0	...
No. 159 Okla. crude oil	1/8	.....	10	10	40	100	..	..	..	..	..	..	..	0	...
No. 174 Okla. crude oil well aired	1/8	.....	10	0	10	10	10	10	50	50	60	60	60	10	...
No. 9 Lard oil	1/4	31.51	10	0	30	30	50	50	90	90	90	90	90	1	100
No. 11 Fish oil	1/4	20	10	0	40	40	70	70	70	90	90	90	90	0	...
No. 16 Knochen oil	1/4	35.88	10	0	10	10	20	20	20	30	40	50	50	9	77
No. 10 Cottonseed oil	1/4	26.66	10	0	20	20	20	20	80	80	80	80	80	1	0
No. 17 Olive oil	1/4	31.82	9	0	0	0	0	0	0	0	11	11	22	27	52
No. 18 Peanut oil	1/4	.....	9	0	0	0	0	0	22	22	22	22	22	21	71
No. 19 Rape-seed oil	1/4	.....	9	66	100	..	..	..	..	..	..	..	..	0	...
No. 313 Rancid palm oil	1/8	.....	10	0	0	0	0	0	0	0	0	0	10	11	22
No. 7 Check	..	.....	10	0	10	10	10	20	20	20	..	..	..	43	51
No. 12 Check	..	.....	10	0	20	20	30	30	30	30	30	30	30	35	26
No. 22 Check	..	.....	9	0	0	0	0	0	11	11	11	11	11	9	74
No. 29 Check	..	.....	10	0	0	0	0	0	0	0	0	0	0	67	75

to leave oily cloth, such lice were again placed upon the cloth, at each feeding. The results were as follows:

Olive oil killed 50 per cent in 4 days
Cedar oil killed 100 per cent in 20 hours
Castor oil killed 100 per cent in 92 hours
Cod-liver oil killed 100 per cent in 68 hours
Paraffin oil killed 100 per cent in 68 hours
Liquid petrolatum killed 100 per cent in 20 hours
Rape-seed oil killed 100 per cent in 44 hours
Neat's-foot oil killed 50 per cent in 6 days
Lard oil killed 100 per cent in 116 hours
Cotton seed oil killed 50 per cent in 4 days
Commercial oleic acid killed 100 per cent in 20 hours
Raw linseed oil killed 100 per cent in 63 hours
Boiled linseed oil killed 100 per cent in 63 hours
Whale oil killed 100 per cent in 63 hours
Fish oil killed 100 per cent in 15 hours
Peanut oil killed 100 per cent in 39 hours

In these first experiments the quantity of oil was not measured. To determine the effect of definite quantities of oils, the experiments tabulated in Table IX were conducted. Different lubricating oils designated as EPMO, PPO, WMO, Cylvalette, etc., and animal and vegetable oils were used. The viscosities of these oils measured at room temperature by a stalagmometer are given, the viscosity of water being taken as 1.

The results with the oils were in general not favorable, unless a large quantity of the oil was present. The proportion of $\frac{1}{8}$ c.c. to 1 sq. in. of the cloth, which is just sufficient to make it oily to the touch, did not give good results.

Inorganic chemicals.—A number of inorganic chemicals were next studied, among which were some soluble only in water, others were oil soluble, and a few were used dissolved in PPO, a light lubricating oil. The only really effective chemical was a saturated solution of bichloride of mercury. Mr. Herbert P. Pearson, a textile expert, considering that lice are not usually found in felt hats impregnated with mercury compounds, prepared for study a number of pieces of cloth impregnated with mercury compounds. The object to be attained in his impregnation was stated to be the union of mercurous oxide or mercury metal with the keratin of the cloth. Series A was impregnated by a two-bath process on wool shirting, the mercuric chloride being applied hot and sodium formate cold, in the proportion 27:15 by weight in the same volume of water. After the two impregnations, the samples were dried on a cylinder heated to 220° F., washed in hot water, and redried. There would, therefore, be no free mercuric chloride on the cloth. Series B was impregnated by a one-bath process using mercuric chloride and acid sodium formate. Series C, D, and E were impregnations of cotton nainsook using the same process

TABLE X

IMPREGNATION WITH INORGANIC CHEMICALS

Chemical	Quantity	No. of lice	Percentage dead in different periods of time (hours) 12	24	36	48	60	72	84	96	108	120	No. of eggs laid	Per cent of eggs hatched
No. 28 Copper oleate	Sat. sol. in PPO. 1/8 c.c. to 1 sq. in.	9	0	0	0	11	11	22	22	33	33	33	26	27
No. 31 Zinc stearate	"	10	0	10	10	20	30	40	40	50	50	50	12	69
No. 30 Sulphur	"	10	0	20	20	20	20	20	20	20	40	50	22	95
No. 32 Sulphur	"	10	10	20	20	30	30	40	40	40	40	60	12	50
No. 331 Copper sulphate	2% Aqueous	10	0	0	0	10	10	10	10	10	10	10	7	100
No. 332 Zinc chloride	" "	10	0	0	0	0	0	0	0	20	20	30	5	80
No. 333 Ferric chloride	" "	10	10	10	30	30	40	40	40	40	40	60	1	0
No. 334 Ferrous sulphate	" "	10	0	0	0	0	20	30	30	30	30	30	0	...
No. 335 Sodium arsenite	" "	10	30	30	70	100	..	..	..	..	..	..	0	...
No. 336 Sodium hydroxide	" "	10	0	0	0	0	0	0	0	0	0	0	16	31
No. 337 Silver nitrate	" "	10	0	0	50	70	70	90	90	90	90	90	0	...
No. 340 Mercuric bichloride	Saturated aqueous	10	100	..	..	..	..	..	..	..	..	..	0	...
No. 316 Lead acetate	Saturated aqueous	10	0	30	70	80	80	80	80	80	80	90	3	0
No. 562 A1 Mercuric chloride	1:15	10	0	10	30	60	60	60	..	..	..	..	6	no record
No. 563 A2 Mercuric chloride	1:25	10	0	0	0	0	0	10	..	..	..	..	5	no record
No. 564 A3 Mercuric chloride	1:50	10	0	0	0	0	0	10	..	..	..	..	21	no record
No. 565 A4 Mercuric chloride	1:100	10	0	0	0	20	20	20	..	..	..	..	16	no record
No. 566 B1 Mercuric chloride	1:250	10	0	0	0	0	0	0	..	..	..	..	14	no record
No. 567 C1 Mercuric chloride	Cotton nainsook treated. Proportion unknown	10	0	0	0	0	10	10	..	..	..	..	19	no record

TABLE X—*Continued*

IMPREGNATION WITH INORGANIC CHEMICALS

Chemical	Quantity	No. of lice	Percentage dead in different periods of time (hours) 12	24	36	48	60	72	84	96	108	120	No. of eggs laid	Per cent of eggs hatched
No. 568 D1 Mercuric chloride	Cotton nainsook treated. Proportion unknown	10	0	0	0	0	0	0	..	..	..	..	16	no record
No. 568 E1 Mercuric chloride	Cotton nainsook treated. Proportion unknown	10	0	0	10	10	10	10	..	..	..	..	10	no record
H4 Mercuric chloride	.5% solution	5	0	10	20	20	..	..	..	..	..	..	6	no record
H5 Mercuric chloride	.2% solution.	5	0	10	10	10	..	..	..	..	..	..	1	no record
H6 Mercuric chloride	.1% solution	5	0	0	10	10	..	..	..	..	..	..	4	no record
K2 Mercuric chloride	.25% solution	5	100	..	..	..	..	..	..	..	..	..	3	no record
K2 Mercuric chloride	.25% solution	5	10	10	10	10	..	..	..	..	..	..	immature	
K4 Mercuric chloride	.2% solution	5	0	20	20	20	20	..	..	..	..	..	7	no record
L2 Mercuric chloride	.25% solution	4	0	0	0	0	..	..	..	..	..	..	3	no record
L3 Colloidal mercuric hydroxide	1–500	4	0	0	10	10	..	..	..	..	..	..	5	no record
L4 Colloidal emulsion of aluminum stearate 4% and phenol 1%	.....	4	0	0	0	10	..	..	..	..	..	..	3	no record
L5 Aluminum stearate 2% phenol ½%	.....	4	0	0	0	0	..	..	..	..	..	..	..	...
No. 29 Check	.....	10	0	0	0	0	0	0	0	0	0	0	67	75
No. 36 Check	.....	10	0	0	0	0	0	0	0	0	0	0	43	33
No. 338 Check	.....	10	0	0	0	0	0	0	10	10	10	10	61	61
No. 570 Check	.....	10	0	0	0	0	0	10	..	..	..	..	12	no record

as Series B. The strength of the solutions used was not given except that the K series was considered a better impregnation than the H series Nothing is known of the L series other than the data given in the table.

The results of these impregnations were not favorable, possibly due to the chemical union of the mercury with the keratin. To be effective, the mercury salt would have to be free, and in such a state would be too dangerous to be worn by the soldier. The observation that the clothes louse is seldom found upon felt hats is no doubt explained by the fact that the head is not their natural habitat.

Active organic chemicals dissolved in oil.—From the results of other experiments[58] it was found that oils wet and spread over the chitinous exoskeleton of the insect, hence it would appear that if an active chemical was dissolved in the oil this chemical would be brought into closer contact with the chitin and would have a better opportunity of penetrating and causing the death of the insect. This series contained organic acids, derivatives containing iodine, alkaloids, and organic bases; anthracene and other hydrocarbons usually found with it,[59] naphthalene and naphthalene derivatives, nitro and hydroxyl derivatives, and a few general chemicals classified as sweet-smelling aromatics. The chemicals were dissolved in light lubricating oils and except where the chemical was quite soluble in the oil, a saturated solution was used. To insure obtaining a saturated solution, the oil and chemical were warmed somewhat and then allowed to cool. The undissolved chemicals often held in suspension by the cool oil were thrown down by centrifuging for a few minutes. An even distribution of the oil over the cloth was obtained by dissolving the required amount of the oil solution in ether and then applying the ether solution to the underwear. In a few minutes the ether evaporated, leaving the oil and chemical on the cloth. The treated underwear was then cut into small pieces, placed in a vial 2½ x 1 inch, the lice added and the open vial placed in the incubator. Every 12 hours they were examined, and the living lice fed. When all the lice were dead in an experiment, they were removed and the uncovered vial remained on the laboratory table until the experiment was repeated. By thus conducting a number of experiments with the same piece of underwear, it was hoped to obtain some idea of the lasting properties of the chemicals as well as their toxicity. (Table XI.) Some of the preparations killed during the first day or two, after which they failed to kill, the oil being left without its toxic principle, due to the evaporation of the chemical. Other cases may be noted where a relatively non-volatile chemical killed quickly during the first day or two, after which it killed slowly or not at all. Such results were due to more volatile impurities which evaporated, leaving the less volatile and slow-killing chemical behind.

[58] Physical Properties Governing the Efficacy of Contact Insecticides.

[59] Dr. F. W. Sperr kindly supplied a number of by-products of the manufacture of coke for use in these experiments.

TABLE XI

IMPREGNATION WITH ACTIVE CHEMICALS DISSOLVED IN OILS

	Total	Percentage dead in hours									Total eggs	Per cent hatched
		12	24	36	48	60	72	84	96	108	120		
Organic acids													
No. 108 Salicylic acid sat. sol. in EPMO 1 c.c.—8 sq. in.	10	90	100	..	..	..	..	..	..	..	..	0	..
No. 132 No. 108, 24 hours old	10	0	70	90	90	90	90	90	90	90	90	0	..
No. 111 Oleic acid in WMO—5% 1 c.c.—8 sq. in.	10	0	0	0	0	10	10	10	10	10	20	36	61
No. 58 Valeric acid 3 c.c. in 3 c.c. EPMO 1 c.c.—8 sq. in.	10	100	..	..	..	..	..	..	..	..	..	0	..
No. 62 No. 58, 24 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
No. 63 No. 58, 48 hrs. old	10	70	80	90	90	90	90	90	90	90	90	0	..
No. 170 Cinnamic acid in PPO sat. sol. 1 c.c.—8 sq. in.	10	0	0	0	0	0	0	0	0	0	0	10	91.6
Iodine derivatives													
No. 34 Iodoform in PPO sat. sol. 1 c.c.—8 sq. in.	10	100	..	..	..	..	..	..	..	..	..	0	..
No. 38 No. 34, 24 hrs. old	10	90	100	..	..	..	..	..	..	..	..	0	..
No. 43 No. 34, 48 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
No. 47 No. 34, 72 hrs. old	10	10	70	70	90	100	..	..	..	..	..	0	..
No. 51 No. 34, 120 hrs. old	10	0	80	80	80	90	90	100	..	..	..	0	..
No. 64 No. 34, 216 hrs. old	10	0	0	0	80	80	100	..	..	..	..	0	..
No. 102 No. 34, 384 hrs. old	10	0	20	60	80	90	100	..	..	..	..	0	..
No. 189 No. 34, 720 hrs. old	10	0	10	10	50	90	90	90	90	90	90	0	..
No. 119 Phenyl iodide in WMO 1 c.c.—8 sq. in.	10	100	..	..	..	..	..	..	..	..	..	0	..
No. 134 No. 119, 24 hrs. old	10	0	0	0	50	70	90	90	90	90	90	0	..
No. 185 Thymol iodide in PPO sat. sol. 1 c.c.—8 sq. in.	10	0	0	0	0	0	0	0	20	20	20	immature	
Alkaloids and organic bases													
No. 39 Cinchonine in PPO sat. sol. 1 c.c.—8 sq. in.	10	0	0	0	10	30	30	30	30	30	30	16	63
No. 54 Morphine in EPMO sat. sol. 1 c.c.—8 sq. in.	10	0	0	10	10	10	10	10	20	20	30	13	23
No. 56 Strychnine in EPMO sat. sol. 1 c.c.—8 sq. in.	12	0	0	0	0	0	8	8	8	8	11	11	22
No. 55 Urea in EPMO sat. sol. 1 c.c.—8 sq. in.	12	0	0	0	0	0	0	0	42	42	50	4	50
Anthracene and related compounds													
No. 75 Anthracene c.p. in EPMO sat. sol. 1 c.c.—8 sq. in.	10	0	0	0	0	0	0	0	0	0	0	8	62.5
No. 74 Anthracene c.p. in EPMO sat. sol. 1 c.c.—8 sq. in.	10	10	10	20	20	40	40	40	50	60	60	0	..
No. 69 Anthracene crude sat. sol. EPMO 1 c.c.—8 sq. in.	10	100	..	..	..	..	..	..	..	..	..	0	..
No. 78 No. 69 24 hrs. old	10	0	100	..	..	..	..	..	..	..	..	0	..
No. 81 No. 69 48 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
No. 87 No. 69 72 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
No. 95 No. 69 96 hrs. old	10	0	90	90	100	..	..	..	..	..	..	0	..
No. 118 No. 69 118 hrs. old	10	0	70	70	100	..	..	..	..	..	..	0	..
No. 156 No. 69 264 hrs. old	5	20	40	40	60	80	80	80	100	..	..	0	..

TABLE XI—*Continued*

IMPREGNATION WITH ACTIVE CHEMICALS DISSOLVED IN OILS

No.	Total	Percentage dead in hours 12	24	36	48	60	72	84	96	108	120	Total eggs	Per cent hatched
Anthracene and related compounds													
90 Dry crude anthracene in crude oil Pa. 1 c.c.—8 sq. in.	10	100	..	..	..	..	..	..	..	..	..	0	..
99 No. 90 24 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
68 Anthracene oil 5% in EPMO 1 c.c.—8 sq. in.	10	100	..	..	..	..	..	..	..	..	..	0	..
77 No. 68 24 hrs. old	10	0	100	..	..	..	..	..	..	..	..	0	..
82 No. 68 48 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
88 No. 68 72 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
96 No. 68 96 hrs. old	10	0	40	60	100	..	..	..	..	..	..	0	..
117 No. 68 168 hrs. old	10	0	70	70	100	..	..	..	..	..	..	0	..
155 No. 68 264 hrs. old	5	0	40	100	..	..	..	..	..	..	..	0	..
172 No. 68 360 hrs. old	10	0	0	0	10	10	20	20	30	60	60	12	0
19 Residue from Alc. ext. of crude anthracene in EPMO sat. sol. 1 c.c.—8 sq. in.	10	100	..	..	..	..	..	..	..	..	..	0	..
91 1st Alc. ext. of crude anthracene in EPMO 1 c.c.—8 sq. in.	10	100	..	..	..	..	..	..	..	..	..	0	..
100 3d Alc. ext. in EPMO 1 c.c.—8 sq. in.	10	100	..	..	..	..	..	..	..	..	..	0	..
100A No. 100 24 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
94 Residue from caustic potash extraction in EPMO 1 c.c.—8 sq. in.	10	100	..	..	..	..	..	..	..	..	..	0	..
104 Caustic potash extract of crude anthracene in EPMO 1. c.c. —8 sq. in.	10	0	0	10	70	70	70	70	70	70	70	0	..
175 Residue from H_2SO_4 extraction in PPO 1 c.c.—8 sq. in	10	100	..	..	..	..	..	..	..	..	..	0	..
211 H_2SO_4 Extract of crude anthracene in PPO 1 c.c.—8 sq. in.	10	10	50	70	100	..	..	..	..	..	..	0	..
70 Diphenyl sat. sol. in EPMO 1 c.c.—8 sq. in.	10	0	100	..	..	..	..	..	..	..	..	0	..
79 No. 70 24 hrs. old	10	0	100	..	..	..	..	..	..	..	..	0	..
83 No. 70 48 hrs. old	10	0	60	80	90	90	100	..	..	..	..	0	..
106 No. 70 96 hrs. old	10	90	100	..	..	..	..	..	..	..	..	0	..
126 No. 70 168 hrs. old	10	90	90	100	..	..	..	..	..	..	..	0	..
161 No. 70 288 hrs. old	10	0	70	100	..	..	..	..	..	..	..	0	..
171 No. 70 360 hrs. old	10	0	30	40	90	90	90	100	..	..	..	0	..
71 Paracoumarone sat. sol. in EPMO 1 c.c.—8 sq. in.	10	0	0	0	0	0	0	20	20	50	50	18	..
73 Coal tar oil 10% in EPMO 1 c.c.—8 sq. in.	10	100	..	..	..	..	..	..	..	..	..	0	..
73A No. 73 24 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
80 No. 73 48 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
86 No. 73 72 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
97 No. 73 96 hrs. old	10	0	90	100	..	..	..	..	..	..	..	0	..

TABLE XI—*Continued*

IMPREGNATION WITH ACTIVE CHEMICALS DISSOLVED IN OILS

	Total	Percentage dead in hours										Total eggs	Per cent hatched
		12	24	36	48	60	72	84	96	108	120		
Anthracene and related compounds													
No.													
116 No. 73 168 hrs. old	10	0	70	90	100	..	..	..	..	..	..	0	..
162 No. 73 288 hrs. old	10	0	50	50	60	100	..	..	..	..	..	0	..
176 No. 73 384 hrs. old	10	0	0	0	0	20	30	60	60	60	80	0	..
114 10% Alkaline ext. of low tar B.P. 270°–365° in WMO 1 c.c. —8 sq. in	10	100	..	..	..	..	..	..	..	..	..	0	..
129 No. 114 24 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
142 No. 114 72 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
152 No. 114 96 hrs. old	5	100	..	..	..	..	..	..	..	..	..	0	..
166 No. 114 168 hrs. old	10	80	100	..	..	..	..	..	..	..	..	0	..
177 No. 114 216 hrs. old	10	30	100	..	..	..	..	..	..	..	..	0	..
194 No. 114 264 hrs. old	10	50	100	..	..	..	..	..	..	..	..	0	..
205 No. 114 312 hrs. old	10	70	70	100	..	..	..	..	..	..	..	0	..
219 No. 114 360 hrs. old	10	0	90	90	90	90	90	90	90	90	90	0	..
Naphthalene and derivatives													
13 10% Naph. in PPO 1 c.c.—8 sq. in	10	100	..	..	..	..	..	..	..	..	..	0	..
23 No. 13 24 hrs. old	10	0	0	10	20	30	30	30	60	70	70	22	82
33 Alpha naphthylamine sat. sol. in PPO 1 c.c.—8 sq. in	10	100	..	..	..	..	..	..	..	..	..	0	..
41 No. 33 48 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
45 No. 33 72 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
49 No. 33 96 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
52 No. 33 120 hrs. old	10	100	..	..		..	..	..	..	..	..	0	..
60 No. 33 144 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
65 No. 33 216 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
69 No. 33 240 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
103 No. 33 384 hrs. old	10	0	0	100	..	..	..	..	..	..	..	0	..
125 No. 33 456 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
188 No. 33 720 hrs. old	10	0	100	..	..	..	..	..	..	..	..	0	..
76 Sulphonated naphthalene sat. sol. EPMO 1 c.c.—8 sq. in.	10	0	0	0	0	10	30	30	30	30	30	2	100
105 Tetrachlornaphthalene (add comp) in WMO 1 c.c.—8 sq. in.	10	0	30	30	60	70	80	80	100	..	..	0	..
186 Chlorinated naphthalene in PPO 1 c.c.—8 sq. in	10	0	0	10	20	20	90	90	90	90	100	Imm.	..
225 No. 186 168 hrs. old	10	0	0	10	10	10	20	40	40	40	40	0	..
196 Dichlorinated naphthalene in PPO 1 c.c.—8 sq. in	10	60	100	..	..	..	..	..	..	..	..	0	..
207 No. 196 48 hrs. old	10	40	100	..	..	..	..	..	..	..	..	0	..
222 No. 196 96 hrs. old	10	10	100	..	..	..	..	..	..	..	..	0	..

TABLE XI—*Continued*

IMPREGNATION WITH ACTIVE CHEMICALS DISSOLVED IN OILS

	Total	Percentage dead in hours										Total eggs	Per cent hatched
		12	24	36	48	60	72	84	96	108	120		
Naphthalene and derivatives													
No.													
229 No. 196 144 hrs. old	10	0	0	70	100	..	..	..	..	..	..	0	..
247 No. 196 240 hrs. old	10	30	90	100	..	..	..	..	..	..	..	0	..
286 No. 196 336 hrs. old	10	60	60	100	..	..	..	..	..	..	..	0	..
110 Betanaphthol sat. sol. WMO 1 c.c.—8 sq. in	10	0	100	..	..	..	..	..	..	..	..	0	..
136 No. 110 24 hrs. old	10	10	10	10	60	60	100	..	..	..	..	0	..
109 Alphanaphthol sat. sol. WMP 1 c.c.—8 sq. in	10	90	100	..	..	..	..	..	..	..	..	0	..
135 No. 109 24 hrs. old	10	0	100	..	..	..	..	..	..	..	..	0	..
154 No. 109 96 hrs. old	5	100	..	..	..	..	..	..	..	..	..	0	..
163 No. 109 168 hrs. old	10	10	90	100	..	..	..	..	..	..	..	0	..
178 No. 109 216 hrs. old	10	0	70	70	100	..	..	..	..	..	..	0	..
199 No. 109 288 hrs. old	10	10	100	..	..	..	..	..	..	..	..	0	..
210 No. 109 336 hrs. old	10	0	100	..	..	..	..	..	..	..	..	0	..
218 No. 109 360 hrs. old	10	0	100	..	..	..	..	..	..	..	..	0	..
253 No. 109 528 hrs. old	10	0	60	80	90	90	100	..	..	..	..	0	..
Nitro compounds													
57 Paranitrophenol sat. sol. in EPMO 1 c.c.—8 sq. in	10	0	0	0	0	0	0	0	0	0	0	68	35
24 Ortho nitranilin sat. sol. in PPO 1 c.c.—8 sq. in	10	100	..	..	..	..	..	..	..	..	..	0	..
35 No. 24 24 hrs. old	10	80	100	..	..	..	..	..	..	..	..	0	..
37 No. 24 48 hrs. old	10	80	100	..	..	..	..	..	..	..	..	0	..
44 No. 24 72 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
48 No. 24 96 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
50 No. 24 120 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
53 No. 24 144 hrs. old	10	0	100	..	..	..	..	..	..	..	..	0	..
61 No. 24 168 hrs. old	10	0	100	..	..	..	..	..	..	..	..	0	..
66 No. 24 240 hrs. old	10	0	90	100	..	..	..	..	..	..	..	0	..
101 No. 24 408 hrs. old	10	0	80	100	..	..	..	..	..	..	..	0	..
130 No. 24 480 hrs. old	10	70	70	70	80	80	80	80	80	90	90	0	..
107 No. 24 432 hrs. old WMO oil 1 c.c.—8 sq. in	10	40	40	50	100	..	..	..	..	..	..	0	..
Sweet-smelling aromatic compounds													
112 Coumarin sat. sol. in WMO 1 c.c.—8 sq. in	10	100	..	..	..	..	..	..	..	..	..	0	..
131 No. 112 24 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
147 No. 112 72 hrs. old	10	90	100	..	..	..	..	..	..	..	..	0	..
160 No. 112 120 hrs. old	10	60	100	..	..	..	..	..	..	..	..	0	..

TABLE XI—*Continued*

IMPREGNATION WITH ACTIVE CHEMICALS DISSOLVED IN OILS

	Total	Percentage dead in hours									Total eggs	Per cent hatched
		12	24	36	48	60	72	84	96	108	120		
Sweet-smelling aromatic compounds													
No.													
173 No. 112 192 hrs. old	10	0	100	..	..	..	..	..	..	..	..	0	..
183 No. 112 240 hrs. old	10	0	70	80	80	90	90	100	..	..	..	0	..
208 No. 112 336 hrs. old	10	0	100	..	..	..	..	..	..	..	..	0	..
217 No. 112 360 hrs. old	10	0	90	100	..	..	..	..	..	..	..	0	..
252 No. 112 528 hrs. old	10	20	40	80	100	..	..	..	..	..	..	0	..
195 Vanillin sat. sol. in PPO 1 c.c.—8 sq. in	10	0	0	0	0	10	10	10	10	10	20	0	..
121 Heliotropine sat. sol. in WMO 1 c.c —8 sq. in	10	100	..	..	..	..	..	..	..	..	..	0	..
133 No. 121 24 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
145 No. 121 72 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
153 No. 121 96 hrs. old	5	100	..	..	..	..	..	..	..	..	..	0	..
165 No. 121 168 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
182 No. 121 216 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
190 No. 121 264 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
201 No. 121 312 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
214 No. 121 360 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
249 No. 121 528 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
Phenols and phenol derivatives													
123 10% creosote in WMO 1 c.c.—8 sq. in	10	100	..	..	..	..	..	..	..	..	..	0	..
139 No. 123 24 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
143 No. 123 72 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
149 No. 123 96 hrs. old	5	100	..	..	..	..	..	..	..	..	..	0	..
168 No. 123 168 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
180 No. 123 216 hrs. old	10	90	100	..	..	..	..	..	..	..	..	0	..
191 No. 123 264 hrs. old	10	80	100	..	..	..	..	..	..	..	..	0	..
204 No. 123 312 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
216 No. 123 360 hrs. old	10	80	100	..	..	..	..	..	..	..	..	0	..
251 No. 123 528 hrs. old	10	40	40	90	90	90	100	..	..	..	..	0	..
122 10% creosote 10% oleic acid in WMO 1 c.c.—8 sq. in	10	100	..	..	..	..	..	..	..	..	..	0	..
140 No. 122 24 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
146 No. 122 72 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
150 No. 122 96 hrs. old	5	100	..	..	..	..	..	..	..	..	..	0	..
167 No. 122 168 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
181 No. 122 216 hrs. old	10	40	100	..	..	..	..	..	..	..	..	0	..
192 No. 122 264 hrs. old	10	70	100	..	..	..	..	..	..	..	..	0	..
203 No. 122 312 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..

TABLE XI—*Continued*

IMPREGNATION WITH ACTIVE CHEMICALS DISSOLVED IN OILS

Phenols and phenol derivatives	Total	Percentage dead in hours									Total eggs	Per cent hatched
		12	24	36	48	60	72	84	96	108	120		
No.													
215 No. 122 360 hrs. old	10	70	100	..	..	..	..	..	..	..	..	0	..
250 No. 122 528 hrs. old	10	20	50	60	80	80	90	100	..	..	..	0	..
113 Pearson's creolin in WMO 10% sol. 1 c.c.—8 sq. in	10	100	..	..	..	..	..	..	..	..	..	0	..
128 No. 113 24 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
151 No. 113 96 hrs. old	5	100	..	..	..	..	..	..	..	..	..	0	..
164 No. 113 168 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
171 No. 113 216 hrs. old	10	80	100	..	..	..	..	..	..	..	..	0	..
193 No. 113 264 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
202 No. 113 312 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
213 No. 113 360 hrs. old	10	70	100	..	..	..	..	..	..	..	..	0	..
248 No. 113 528 hrs. old	10	40	50	50	60	100	..	..	..	..	..	0	..
198 Tricresol 10% sol. in PPO 1 c.c.—8 sq. in	10	100	..	..	..	..	..	..	..	..	..	0	..
209 No. 198 48 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
221 No. 198 96 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
227 No. 198 144 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
246 No. 198 240 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
365 No. 198 288 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
109 Alphanaphthol sat. sol. in WMO 1 c.c.—8 sq. in	10	90	100	..	..	..	..	..	..	..	..	0	..
Betanaphthol. See under Naphthalene Comp.													
120 Guaiacol carbonate sat. sol. in WMO 1 c.c.—8 sq. in	10	0	0	0	10	20	20	20	20	20	30	64	39
148 Phenyl salicylate 25% sol. in PPO 1 c.c.—8 sq. in	10	0	40	60	100	..	..	..	..	..	..	0	..
Phenyl iodide. See under Iodine.													
Thymol iodide. See under Iodine.													
197 Tribromphenol sat. sol. in PPO 1 c.c.—8 sq. in	10	100	..	..	..	..	..	..	..	..	..	0	..
206 No. 197 48 hrs. old	10	10	100	..	..	..	..	..	..	..	..	0	..
223 No. 197 96 hrs. old	10	60	100	..	..	..	..	..	..	..	..	0	..
228 No. 197 144 hrs. old	10	0	100	..	..	..	..	..	..	..	..	0	..
236 No. 197 192 hrs. old	10	0	100	..	..	..	..	..	..	..	..	0	..
245 No. 197 197 hrs. old	10	0	40	40	90	100	..	..	..	..	..	0	..
57 Paranitrophenol sat. sol. in EPMO 1 c.c.—8 sq. in	10	0	0	0	0	0	0	0	0	0	0	68	35
383 Eugenol without oil	10	100	..	..	..	..	..	..	..	..	..	0	..
384 Carvacrol without oil	10	100	..	..	..	..	..	..	..	..	..	0	..
385 Thymol without oil	10	100	..	..	..	..	..	..	..	..	..	0	..
427 Orthocresol benzoate 10% in PPO	10	10	40	90	90	90	100	..	..	..	..	0	..
431 Biphenol without oil	10	0	10	10	20	20	30	30	30	30	40	35	..

TABLE XI—*Continued*

IMPREGNATION WITH ACTIVE CHEMICALS DISSOLVED IN OILS

No.	Phenols and phenol derivatives	Total	Percentage dead in hours 12	24	36	48	60	72	84	96	108	120	Total eggs	Per cent hatched
59	Check for No. 54–58	10	0	0	0	0	0	0	0	0	0	0	60	40
72	" " " 68–73	10	0	0	0	0	0	0	0	10	20	20	30	30
92	" " " 89–91	10	0	10	10	20	30	30	30	30	30	30	33	67
115	" " " 109–118	10	0	0	0	10	10	10	10	20	20	20	64	55
124	" " " 119–126	10	0	0	0	10	10	10	20	20	20	20	84	49
141	" " " 131–140	10	0	0	0	0	0	10	10	10	10	10	93	68
148	" " " 142–147	10	0	0	0	20	20	20	20	20	20	20	67	82
157	" " " 149–156	10	0	0	10	10	10	10	10	10	20	20	82	85
169	" " " 163–168	10	0	0	0	0	0	0	0	0	0	0	92	80
187	" " " 183–186	10	0	0	0	10	10	20	30	30	30	30	57	72
200	" " " 195–199	10	0	0	0	0	0	0	0	10	10	10	90	87
212	" " " 206–211	10	0	0	0	0	0	0	0	0	0	0	54	82
220	" " " 213–219	10	0	0	0	10	10	10	10	10	10	10	82	64
226	" " " 221–225	10	0	0	10	10	10	10	20	20	20	20	98	79
232	" " " 227–231	10	0	0	0	0	10	10	10	10	10	20	61	92
244	" " " 241–243	10	10	10	10	20	20	20	20	20	20	20	100	86
256	" " " 245–255	10	0	0	0	0	0	0	0	0	0	10	102	84
263	" " " 257–262	10	0	0	0	0	0	0	0	0	0	0	141	84
273	" " " 265–272	10	0	0	0	0	0	0	0	10	10	20	24	96
300	" " " 298–301	10	0	0	0	0	0	0	0	0	0	0	63	13
309	" " " 301–308	10	0	0	0	10	10	10	10	10	10	40	75	44
312	" " " 310–314	10	0	0	0	0	0	0	0	0	0	0	87	68
330	" " " 321–329	10	0	0	0	0	0	0	0	10	10	10	47	66
338	" " " 331–339	10	0	0	0	0	0	0	10	10	10	10	61	61
347	" " " 343–346	10	0	10	10	10	10	10	10	10	10	10	52	90
350	" " " 348–349	10	0	0	0	0	0	0	0	0	0	0	103	71
353	" " " 351–352	10	0	0	0	0	0	10	10	10	10	10	62	58
356	" " " 354–355	10	0	0	0	0	0	0	0	0	0	0	74	61
359	" " " 357–358	10	0	0	0	0	0	0	0	0	0	0	90	53
362	" " " 360–365	10	0	0	0	0	0	0	0	0	0	10	47	23
369	" " " 366–368	10	0	0	0	0	0	0	0	0	0	0	40	68
376	" " " 375–377	10	0	0	0	0	0	0	0	0	0	0	93	54
381	" " " 378–380	10	0	0	0	0	0	0	0	0	0	0	37	38
388	" " " 384–387	20	0	0	20	20	20	20	20	20	20	20	83	30
405	" " " 400–404	20	0	0	0	0	0	0	0	0	0	0	12	25

Lasting properties when worn.—The above experiments were at best but a poor index of the lasting properties of the chemical when worn. Further data upon this point were obtained by selecting a few of the best chemicals for impregnating pieces of cloth, which were then pinned inside the experimenter's underwear and worn next to the skin. The patches were 48 square inches in size and from day to day a piece of this underwear was cut off and its toxicity to lice tested in the incubator. These experiments showed that there was a great difference in lasting properties between the previous experiments and those in which the cloth was actually worn. Further it was apparent that the light lubricating oil used in the experiments was soon taken up by the other clothing, thus greatly reducing the toxicity of the treated cloth. A number of solid, or semisolid fats and greases were used. (Table XII.) Heliotropine was one of the best chemicals, being apparently non-toxic to the skin and lasting as long as 168 hours (no. 344) when used with cocoa butter, in which it was more soluble than in the other fats. Without the oil, heliotropine killed just as rapidly, but having crystallized on the underwear it was soon rubbed off by the friction encountered in wearing.

Toxicity of chemicals with and without oil.—The experiment with heliotropine having shown the oil to be unessential to toxicity, experiments were conducted using other chemicals with and without an oil. (Table XIII.) These results show that the oil is not necessary to the action of the chemical. In a few cases, the better results obtained without the oil were due to the use of larger quantities of the chemical than could be dissolved in the oil.

Impregnation with salts of the phenols.—Since oils were found to be unessential, the question presented itself of converting certain phenols into their non-volatile sodium or calcium salts. These salts decomposed, the original phenol being slowly generated by the action of moisture and carbon dioxide given off by the body. These salts were used to impregnate pieces of underwear which, when dry, were worn as in the previous experiments. When the patches had been worn about 5 or 6 days, it was found necessary to exercise sufficiently to produce perspiration before the phenols were present in large enough quantity to prove toxic to the lice. Thymol, carvacrol, and eugenol were studied to determine if the use of a less volatile phenol would have any influence on the period of effectiveness, but no such influence was noted. Experiments nos. 433 and 437 conducted during the summer show that the phenates are rapidly broken up and will last but 3 days during warm weather.

Bacot's[60] crude phenol soap preparation, which is no doubt a phenate, was tested. Since this preparation has been given field trials, a comparison of the results of these methods with the results in the field could

[60] The Use of Insecticides against Lice.

TABLE XII

LASTING PROPERTIES WHEN WORN

No.	Chemical	Total	Percentage dead in hours									Total eggs	Per cent hatched
			12	24	36	48	60	72	84	96	108	120		
224	10% creosote in PPO. worn 48 hrs.	10	0	0	0	0	0	0	0	0	0	0	Immature	
231	10% creosote in Pa. crude oil worn 24 hrs.	10	0	0	0	0	20	20	20	20	20	20	49	90
258	5 c.c. of 5% sol. of heliotropine in ether to 12 sq. in. of cloth	10	90	100	..	..	..	..	..	..	..	..	0	..
267	No. 258 worn 24 hrs.	10	100	..	..	..	..	..	..	..	..	..	0	..
274	No. 258 worn 48 hrs.	10	100	..	..	..	..	..	..	..	..	..	0	..
280	No. 258 worn 72 hrs.	10	10	70	70	80	80	80	80	80	80	80	0	..
289	No. 258 worn 120 hrs.	10	0	0	0	0	0	0	0	10	10	10	30	..
259	5 c.c. of 5% sol. of heliotropine in ether and 5 grams of cocoa butter.	10	100	..	..	..	..	..	..	..	..	..	0	..
268	No. 259 worn 24 hrs.	10	100	..	..	..	..	..	..	..	..	..	0	..
275	No. 259 worn 48 hrs.	10	100	..	..	..	..	..	..	..	..	..	0	..
281	No. 259 worn 72 hrs.	10	100	..	..	..	..	..	..	..	..	..	0	..
290	No. 259 worn 120 hrs.	10	0	0	0	0	0	0	0	0	0	0	18	6
260	5 c.c. of 5% sol. of heliotropine in ether and 5 grams of spermaceti.	10	90	100	..	..	..	..	..	..	..	..	0	..
269	No. 260 worn 24 hrs	10	100	..	..	..	..	..	..	..	..	..	0	..
276	No. 260 worn 48 hrs.	10	90	100	..	..	..	..	..	..	..	..	0	..
282	No. 260 worn 72 hrs.	10	100	..	..	..	..	..	..	..	..	..	0	..
291	No. 260 worn 120 hrs	10	0	0	10	10	10	10	10	10	10	10	45	9
261	5 c.c. of 5% heliotropine in ether and 5 grams of vaseline	10	100	..	..	..	..	..	..	..	..	..	0	..
270	No. 261 worn 24 hrs	10	100	..	..	..	..	..	..	..	..	..	0	..
277	No. 261 worn 48 hrs	10	70	100	..	..	..	..	..	..	..	..	0	..
283	No. 261 worn 72 hrs.	10	90	100	..	..	..	..	..	..	..	..	0	..
292	No. 261 worn 120 hrs.	10	0	0	0	0	0	0	0	0	0	0	30	3
262	5 c.c. of 5% sol. of heliotropine in ether and 5 grams of beeswax.	10	100	..	..	..	..	..	..	..	..	..	0	..
271	No. 262 worn 24 hrs	10	100	..	..	..	..	..	..	..	..	..	0	..
278	No. 262 worn 48 hrs	10	50	60	100	..	..	..	..	..	..	..	0	..
284	No. 262 worn 72 hrs.	10	100	..	..	..	..	..	..	..	..	..	0	..
293	No. 262 worn 120 hrs	10	0	0	30	30	30	30	30	30	30	30	1	..
264	5 c.c. of 5% of sol. of heliotropine in ether and 1 c.c. of cylvalette	10	100	..	..	..	..	..	..	..	..	..	0	..
272	No. 264 worn 24 hrs	10	100	..	..	..	..	..	..	..	..	..	0	..
279	No. 264 worn 48 hrs	10	80	90	100	..	..	..	..	..	..	..	0	..
285	No. 264 worn 72 hrs	10	70	80	80	90	90	90	90	90	90	90	0	..

TABLE XII—*Continued*

LASTING PROPERTIES WHEN WORN

No.	Chemical	Total	Percentage dead in hours									Total eggs	Per cent hatched
			12	24	36	48	60	72	84	96	108	120		
294	No. 264 worn 120 hrs	10	0	0	0	0	0	0	0	0	0	0	20	15
298	20 c.c. of 5% sol. of heliotropine to 48 sq. in. of cloth worn 48 hrs	10	70	70	100	..	..	..	..	..	..	..	0	..
299	5% heliotropine in 10 c.c. of Pa. crude oil in 20 c.c. CS_2 benzene mixture	10	70	70	100	..	..	..	..	..	..	..	0	..
	Records for 310 at 24 and 48 hr. periods lost													
310	1 gram heliotropine 5 grams cocoa butter dissolved in ether to 48 sq. in. cloth worn 72 hrs	10	90	100	..	..	..	..	..	..	..	..	0	..
319	No. 310 worn 96 hrs	10	100	..	..	..	..	..	..	..	..	..	0	..
324	No. 310 worn 120 hrs	10	30	40	60	80	90	90	90	90	100	..	0	..
342	No. 310 worn 144 hrs	10	10	90	90	90	90	90	90	90	90	100	0	..
343	No. 310 worn 168 hrs	10	10	40	40	50	60	60	60	60	90	90	0	..
	Records for 311 at 24 and 48 hr. periods lost													
311	1 gram of heliotropine 3 grams cocoa butter in ether to 48 sq. in. worn 72 hrs	10	90	100	..	..	..	..	..	..	..	..	0	..
318	No. 311 worn 96 hrs	10	100	..	..	..	..	..	..	..	..	..	0	..
323	No. 311 worn 120 hrs	10	80	100	..	..	..	..	..	..	..	..	0	..
341	No. 311 worn 144 hrs	10	20	100	..	..	..	..	..	..	..	..	0	..
344	No. 311 worn 168 hrs	10	0	90	100	..	..	..	..	..	..	..	0	..

TABLE XIII

IMPREGNATION WITH AND WITHOUT OILS

No.	Compounds used without oil	Total	Percentage dead in hours									Total eggs	Per cent hatched
			12	24	36	48	60	72	84	96	108	120		
234	Heliotropine without oil	10	100	..	..	..	..	..	..	..	..	..	0	..
237	No. 234 48 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
254	No. 234 96 hrs. old	10	100	..	..	..	..	..	..	..	..	..	0	..
238	Orthonitranilin without oil	10	0	70	70	70	70	80	80	80	80	80	0	..
302	Benzidine with PPO. 1 c.c.—8 sq. in	10	0	0	0	0	0	0	0	0	10	20	17	88
301	Benzidine without oil	10	0	0	10	10	10	20	20	30	30	40	12	0
368	Resorcinol sat. sol. in PPO. 1 c.c.—8 sq. in	10	0	10	20	20	20	20	20	20	20	20	8	..
372	Resorcinol without oil	10	30	40	60	60	60	70	80	80	90	90	0	..
375	Betanaphthol without oil	10	20	70	70	80	80	80	80	80	90	100	0	..
380	Alphanaphthol without oil	10	10	80	90	90	90	100	..	..	..	..	0	..
109	Alphanaphthol sat. sol. in WMO 1 c.c.—8 sq. in	10	90	100	..	..	..	..	..	..	..	..	0	..
110	Naphthol sat. sol. in WMO 1 c.c.—8 sq. in	10	10	10	10	60	60	100	..	..	..	..	0	..

TABLE XIV

IMPREGNATION WITH PHENATES

No.	Chemical	Total	Percentage dead in hours									Total eggs	Per cent hatched
			12	24	36	48	60	72	84	96	108	120		
322	3% NaOH + 12% creosote ½ c.c. per sq. in	10	100	..	..	..	..	..	..	..	..	..	0	..
345	No. 322 worn 24 hrs	10	100	..	..	..	..	..	..	..	..	..	0	..
348	No. 322 worn 48 hrs	10	100	..	..	..	..	..	..	..	..	..	0	..
351	No. 322 worn 72 hrs	10	40	100	..	..	..	..	..	..	..	..	0	..
354	No. 322 worn 96 hrs	10	100	..	..	..	..	..	..	..	..	..	0	..
357	No. 322 worn 120 hrs	10	60	100	..	..	..	..	..	..	..	..	0	..
360	No. 322 worn 144 hrs	10	60	100	..	..	..	..	..	..	..	..	0	..
366	No. 322 worn 168 hrs	10	0	0	10	40	60	80	80	90	90	100	0	..
370	No. 322 worn 192 hrs	10	100	..	..	..	..	..	..	..	..	..	0	..
373	No. 322 worn 216 hrs	10	100	..	..	..	..	..	..	..	..	..	0	..
378	No. 322 worn 240 hrs	10	0	10	20	30	90	100	..	..	..	..	0	..
321	3% NaOH extract of low tar. ½ c.c. per sq. in	10	100	..	..	..	..	..	..	..	..	..	0	..
346	No. 321 worn 24 hrs	10	30	100	..	..	..	..	..	..	..	..	0	..
349	No. 321 worn 48 hrs	10	60	100	..	..	..	..	..	..	..	..	0	..
352	No. 321 worn 72 hrs	10	30	100	..	..	..	..	..	..	..	..	0	..
355	No. 321 worn 96 hrs	10	10	100	..	..	..	..	..	..	..	..	0	..
358	No. 321 worn 120 hrs	10	10	100	..	..	..	..	..	..	..	..	0	..
361	No. 321 worn 144 hrs	10	100	..	..	..	..	..	..	..	..	..	0	..
367	No. 321 worn 168 hrs	10	0	20	30	30	40	80	80	80	80	90	1	0
371	No. 321 worn 192 hrs	10	10	10	20	50	90	90	90	90	90	90	0	..
374	No. 321 worn 216 hrs	10	90	100	..	..	..	..	..	..	..	..	0	..
379	No. 321 worn 240 hrs	10	40	40	40	40	50	60	100	..	..	..	0	..
385	Thymol 12 grams dissolved in 100 c.c. of 3% NaOH. cloth dipped, worn 24 hrs	10	100	..	..	..	..	..	..	..	..	..	0	..
390	No. 385 worn 48 hrs	10	100	..	..	..	..	..	..	..	..	..	0	..
393	No. 385 worn 72 hrs	10	40	90	90	100	..	..	..	..	..	..	0	..
396	No. 385 worn 96 hrs	10	30	30	100	..	..	..	..	..	..	..	0	..
400	No. 385 worn 120 hrs	10	0	50	50	90	100	..	..	..	..	..	0	..
407	No. 385 worn 144 hrs	10	0	70	100	..	..	..	..	..	..	..	0	..
410	No. 385 worn 168 hrs	10	10	10	100	..	..	..	..	..	..	..	0	..
413	No. 385 worn 192 hrs	10	0	10	100	..	..	..	..	..	..	..	0	..
416	No. 385 worn 216 hrs	10	10	..	100	..	..	..	..	..	..	..	0	..
419	No. 385 worn 240 hrs	10	0	20	30	40	50	60	70	80	80	100	0	..
432	No. 385 worn 264 hrs	10	0	0	0	10	30	60	80	90	100	..	0	..

TABLE XIV—*Continued*

IMPREGNATION WITH PHENATES

No.	Chemical	Total	Percentage dead in hours										Total eggs	Per cent hatched
			12	24	36	48	60	72	84	96	108	120		
384	Carvacrol 12 c.c. to 100 c.c. of 3% NaOH solution cloth dipped, worn 24 hrs	10	100	..	..	..	..	..	..	..	..	..	0	..
389	No. 384 worn 48 hrs	10	100	..	..	..	..	..	..	..	..	..	0	..
392	No. 384 worn 72 hrs	10	80	100	..	..	..	..	..	..	..	..	0	..
395	No. 384 worn 96 hrs	10	100	..	..	..	..	..	..	..	..	..	0	..
401	No. 384 worn 120 hrs	10	0	100	..	..	..	..	..	..	..	..	0	..
408	No. 384 worn 144 hrs	10	0	100	..	..	..	..	..	..	..	..	0	..
411	No. 384 worn 168 hrs	10	100	..	..	..	..	..	..	..	..	..	0	..
414	No. 384 worn 192 hrs	10	0	100	..	..	..	..	..	..	..	..	0	..
417	No. 384 worn 216 hrs	10	40	..	100	..	..	..	..	..	..	..	0	..
418	No. 384 worn 240 hrs	10	0	0	10	20	40	90	90	90	90	90	0	..
422	No. 384 worn 264 hrs	10	0	20	20	40	70	100	..	..	..	..	0	..
391	Eugenol 12 c.c. to 100 c.c. of 3% NaOH solution cloth dipped, worn 24 hrs	10	100	..	..	..	..	..	..	..	..	..	0	..
394	No. 391 worn 48 hrs	10	100	..	..	..	..	..	..	..	..	..	0	..
397	No. 391 worn 72 hrs	10	100	..	..	..	..	..	..	..	..	..	0	..
402	No. 391 worn 96 hrs	10	0	100	..	..	..	..	..	..	..	..	0	..
406	No. 391 worn 120 hrs	10	50	100	..	..	..	..	..	..	..	..	0	..
409	No. 391 worn 144 hrs	10	100	..	..	..	..	..	..	..	..	..	0	..
412	No. 391 worn 168 hrs	10	60	100	..	..	..	..	..	..	..	..	0	..
415	No. 391 worn 192 hrs	10	70	..	100	..	..	..	..	..	..	..	0	..
420	No. 391 worn 216 hrs	10	0	80	90	100	..	..	..	..	..	..	0	..
424	No. 391 worn 240 hrs	10	10	50	50	100	..	..	..	..	..	..	0	..
425	No. 391 worn 264 hrs	10	0	90	100	..	..	..	..	..	..	..	0	..
429	Dipped in Na creosote mixture dried and dipped in 8 c.c Pa. crude oil + 22 c.c. CS_2 to 48 sq. in. worn 92 hrs	10	0	0	0	20	20	50	50	60	70	80	0	..
433	Na creosote mixture worn 48 hrs	10	100	..	..	..	..	..	..	..	..	..	0	..
434	Same as 433 but ½ gram of paraffin MP 52° C dissolved in CS_2 and C_6H_6 added to 48 sq. in worn 48 hrs	10	100	..	..	..	..	..	..	..	..	..	0	..
435	Same as 433 but with 1 gram paraffin added worn 48 hrs.	10	0	20	20	20	20	20	30	30	40	40	85	68
436	Same as 433 but with 3 grams paraffin worn 48 hrs	10	20	30	40	40	40	40	40	40	50	50	72	69
437	No. 433 worn 72 hrs	10	0	10	10	20	20	20	20	20	30	30	60	70
438	No. 434 worn 72 hrs	10	0	0	0	0	0	0	10	10	10	10	56	84

TABLE XIV—*Continued*

IMPREGNATION WITH PHENATES

No.	Chemical	Total	Percentage dead in hours									Total eggs	Per cent hatched
			12	24	36	48	60	72	84	96	108	120		
439	No. 435 worn 72 hrs.	10	0	0	0	10	10	20	30	30	40	40	27	40
440	No. 436 worn 72 hrs.	10	0	10	10	10	10	10	10	10	10	10	40	100
443	Bacot's crude phenol soap 10% phenol worn 48 hrs.	10	40	100	..	..	..	..	..	..	..	..	0	..
445	No. 443 72 hrs. (after perspiration)	10	30	60	100	..	..	..	..	..	..	..	0	..
447	No. 443 96 hrs. (after perspiration)	10	0	10	50	50	100		..	..	..	..	0	..
449	No. 443 120 hrs. (after perspiration)	10	10	10	60	60	60	60	80	80	90	90	0	..
441	3 c.c. of creosote to 48 sq. in. Clothes later dipped in 3-5% suspension of calcium hydroxide 24 hrs. old	10	40	100	..	..	..	..	..	..	..	..	0	..
442	No. 441 96 hrs. old	10	60	100	..	..	..	..	..	..	..	..	0	..
444	No. 441 120 hrs. old (after perspiration)	10	100	..	..	..	..	..	..	..	..	..	..	..
446	No. 441 144 hrs. old	10	60	80	100	..	..	..	..	..	..	..	0	..
448	No. 441 168 hrs. old (after perspiration	10	100	..	..	..	..	..	..	..	..	..	0	..
451	No. 441 192 hrs. old (after perspiration)	10	30	30	30	30	40	60	80	80	90	100	0	..

be obtained. Bacot claims that a treated shirt would retain its insecticidal action for about a week, killing more slowly as time passed, but in these experiments 96 hours appeared to be about its limit of effectiveness.

The phenates might be used to impregnate underwear for winter use, but owing to the large quantities of carbon dioxide given off in the summer, their value is greatly reduced. The search for other non-volatile chemicals which by decomposition would liberate some active pediculicide was not successful; hence a further study of volatile chemicals was undertaken.

TABLE XV

RELATIONSHIP OF BOILING POINT AND VOLATILITY TO TOXICITY

Valeric acid	184°–185°	Kills 100 per cent within 12 hrs.	
Phenyl iodide	188°.....		
Creosote	207°.....		
Naphthalene	218°.....		
Thymol	232°.....		
Carvacrol	237°.....		
Eugenol	242°.....		
Heliotropine	263°.....		
Coumarin	291° Subl.		
Diphenyl	254°.....	Kills 100 per cent within 24 hrs.	
Alphanaphthol	278°–280°		
Phenyl salicylate	172°–173°–12 mm...	Kills 60–100 per cent in 48 hrs.	
Resorcinol	276.5°		
Betanaphthol	285°–286°.....		
Orthocresol benzoate	293°–305°.....		
Cinnanic acid	300°.....	Very slight volatility....	Kills not more than 50 per cent in five days
Anthracene	360°.....		
Benzidine	360°.....		
Thymol iodide	not determined....		
Paranitrophenol	not determined...		
Guiacol carbonate.	Decomposes..		
Copper oleate	not determined.....	Non volatile or nearly so.	
Zinc stearate	not determined.....		

Relation of boiling point of the chemical to toxicity.—Inasmuch as other experiments with insecticides[61] have shown a relationship between the boiling point or the volatility of the chemical and the toxicity of its vapor, it was thought that a similar relationship might exist in these experiments. Table XV gives an arrangement of certain of the chemicals in such a manner as to show this relationship. In general, by increasing the boiling point, i.e., reducing the volatility, the time required to produce the death of the louse is increased. This increase is not necessarily due to a reduced toxicity, but rather to the smaller quantity of the chemical present in an atmosphere saturated with its vapor. Slightly volatile or non-volatile compounds fail to kill. It appears, therefore, that either the chemicals are unable to pass through the chitinous body-wall in any form other than a vapor, or that the chitinous body-wall is impervious to the chemical

[61] Volatility of Organic Compounds as an Index of the Toxicity of Their Vapors to Insects.

in any form, and the chemical must enter the tracheae of the louse as a vapor to reach the thin chitinous walls of the finer tracheae.

From the data thus far presented, the following principles appear to be established; first, that a successful chemical must have a fair degree of volatility to make penetration into the insect's body possible, and second, that its lasting properties depend upon a very low volatility. The best chemical, therefore, must be one of very low volatility, but of very high toxicity, in order that the small amount of vapor which would be able to penetrate the insect would bring about its death. On the other hand, such a chemical must have a low toxicity to man, as otherwise skin irritation would result.

Halogenated cresols.—Cresol and naphthalene have both received favorable notice as pediculicides, and of these two chemicals cresol appears to be the more toxic. It was therefore suggested by one of us (H.) that derivatives of cresol, especially halogenated cresols, might possess the same general toxicity of the cresol but possess a very much reduced volatility. Table XVI gives the details of the insecticidal value of these chemicals and their lasting properties when worn as in the preceding experiments. The introduction of a chlorine into the cresol molecule increases but little its lasting properties, while one bromine gives a decided increase and an iodine even a greater increase. Two chlorines are not equal to one bromine, but two bromines are greater than one iodine, while three bromines make a compound ineffective as a pediculicide. The chemicals giving the best results were the dibromorthocresol, dibrommetacresol, and the dichlormonobrommetacresol, which last nearly two weeks. These chemicals cause a very slight irritation to the skin during the first day or two, due possibly to certain portions which have not been completely brominated. One test was made with the sodium salt of dibromtricresol, but being soluble in water, it was brought into close contact with the skin when the body was perspired, and produced somewhat more irritation than the dibromcresol itself.

The value of chlorine compounds of naphthalene having been previously studied, only the results with monobromnaphthalene, lasting 120 hours, and dibromnaphthalene, which was ineffective, are included in this table.

Determination of volatility.—Inasmuch as the boiling point of a chemical is at best but a rough index of its volatility, an effort was made to devise a simple piece of apparatus to study volatility. At first an attempt was made to study evaporation by playing a stream of air from an electric fan over weighed squares of woolen underwear of equal size, upon which the substances to be tested were dropped. The loss of weight of these squares was determined, but was not uniform. The lack of uniformity in results was due to irregularities in ventilation, owing to lack of uniformity in the air currents.

TABLE XVI

IMPREGNATION WITH HALOGENATED CRESOLS

No.	Chemical	Total	Percentage dead in hours									Total eggs	Per cent hatched
			12	24	36	48	60	72	84	96	108	120		
483	Monochlororthocresol worn 24 hrs.	5	0	0	20	20	20	20	40	40	60	60	13	0
461	Monobromparacresol worn 24 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
465	" worn 48 hrs.	5	80	100	..	..	..	..	..	..	..	..	0	..
468	" worn 72 hrs.	5	0	40	40	60	80	80	80	80	100	..	0	..
471	" worn 96 hrs.	5	0	40	40	60	80	80	80	80	80	80	0	..
474	" worn 120 hrs.	5	20	40	40	80	100	..	..	..	..	..	0	..
477	" worn 144 hrs.	5	20	40	80	100	..	..	..	..	..	..	0	..
480	" worn 168 hrs.	5	0	0	0	0	0	20	40	40	80	80	0	..
493	Monobrommetacresol worn 24 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
495	" worn 48 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
497	" worn 72 hrs.	5	40	60	100	..	..	..	..	..	..	..	0	..
499	" worn 96 hrs.	5	0	0	0	0	0	0	0	0	0	20	Immature	
460	Monoiodoorthocresol worn 24 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
464	" worn 48 hrs.	5	80	100	..	..	..	..	..	..	..	..	0	..
467	" worn 72 hrs.	5	0	100	..	..	..	..	..	..	..	..	0	..
470	" worn 96 hrs.	5	40	80	100	..	..	..	..	..	..	..	0	..
473	" worn 120 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
476	" worn 144 hrs.	5	80	100	..	..	..	..	..	..	..	..	0	..
479	" worn 168 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
482	" worn 192 hrs.	5	40	40	100	..	..	..	..	..	..	..	0	..
486	" worn 216 hrs.	5	0	0	20	40	60	80	80	80	80	100	5	0
490	" worn 240 hrs.	5	0	40	60	60	80	80	80	80	100	..	0	..
510	Dichlororthocresol worn 24 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
532	" worn 48 hrs.	5	0	0	20	20	40	40	40	40	40	40	5	..
454	Dibromorthocresol worn 36 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
456	" worn 72 hrs.	5	0	20	60	100	..	..	..	..	..	..	0	..
458	" worn 96 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
459	" worn 120 hrs.	5	80	100	..	..	..	..	..	..	..	..	0	..
466	" worn 168 hrs.	5	0	80	100	..	..	..	..	..	..	..	0	..
472	" worn 216 hrs.	5	60	80	100	..	..	..	..	..	..	..	0	..
475	" worn 240 hrs.	5	20	100	..	..	..	..	..	..	..	..	0	..
478	" worn 264 hrs.	5	0	20	60	100	..	..	..	..	..	..	0	..
481	Dibromorthocresol worn 288 hrs.	5	20	60	80	80	80	100	..	..	..	..	0	..

TABLE XVI—*Continued*

IMPREGNATION WITH HALOGENATED CRESOLS

No.	Chemical	Total	Percentage dead in hours										Total eggs	Per cent hatched
			12	24	36	48	60	72	84	96	108	120		
485	Dibrommetacresol worn 312 hrs.	5	20	60	60	60	60	60	60	60	60	100	24	0
484	" worn 24 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
488	" worn 48 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
491	" worn 72 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
492	" worn 96 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
494	" worn 120 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
498	" worn 168 hrs.	5	20	40	100	..	..	..	..	..	..	..	0	..
502	" worn 192 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
505	" worn 216 hrs.	5	80	100	..	..	..	..	..	..	..	..	0	..
511	" worn 240 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
514	" worn 264 hrs.	5	0	60	100	..	..	..	..	..	..	..	0	..
519	" worn 288 hrs.	5	40	60	100	..	..	..	..	..	..	..	0	..
521	" worn 312 hrs.	5	0	0	10	40	40	40	40	80	80	80	0	..
453	Tribrommetacresol worn 36 hrs	5	80	100	..	..	..	..	..	..	..	..	0	..
455	" worn 72 hrs.	5	0	0	0	0	0	0	0	0	0	0	23	34
500	Monochlormonobrommetacresol worn 24 hrs.	5	20	80	100	..	..	..	..	..	..	..	0	..
503	" worn 48 hrs.	5	0	20	20	40	40	40	40	40	40	40	11	0
506	" worn 72 hrs.	5	0	0	0	0	0	20	20	40	40	40	58	50
518	Monochlordibrommetacresol worn 24 hrs.	5	40	60	100	..	..	..	..	..	..	..	0	..
533	" worn 48 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
536	" worn 120 hrs.	5	0	20	60	100	..	..	..	..	..	..	0	..
534	Dichlormonobrommetacresol worn 48 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
537	" worn 120 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
539	" worn 144 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
545	" worn 192 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
551	" worn 240 hrs.	5	80	80	100	..	..	..	..	..	..	..	0	..
552	" worn 264 hrs.	5	20	40	100	..	..	..	..	..	..	..	0	..
553	Dichlormonobrommetacresol worn 288 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
555	" worn 312 hrs.	5	80	100	..	..	..	..	..	..	..	..	0	..
560	" worn 336 hrs.	5	60	60	80	80	100	..	..	..	..	..	0	..
561	" worn 360 hrs.	5	20	60	80	100	..	..	..	..	..	..	0	..

TABLE XVI—*Continued*

IMPREGNATION WITH HALOGENATED CRESOLS

No.	Chemical	Total	Percentage dead in hours									Total eggs	Per cent hatched
			12	24	36	48	60	72	84	96	108	120		
523	Dibromtricresol with paraffine worn 96 hrs.	5	80	100	..	..	..	..	..	..	..	..	0	..
525	" " " worn 144 hrs.	5	40	100	..	..	..	..	..	..	..	..	0	..
527	" " " worn 168 hrs.	5	20	20	60	60	100	..	..	..	..	..	0	..
529	" " " worn 216 hrs.	5	0	0	0	40	40	40	80	80	100	..	Immature	
524	Dibromtricresol without paraffine worn 96 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
526	" " " worn 144 hrs.	5	40	100	..	..	..	..	..	..	..	..	0	..
528	" " " worn 168 hrs.	5	40	80	100	..	..	..	..	..	..	..	0	..
530	" " " worn 216 hrs.	5	0	20	20	20	20	20	20	20	60	60	Immature	
531	Dibromcreosote worn 48 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
535	" worn 120 hrs.	5	40	100	..	..	..	..	..	..	..	..	0	..
538	" worn 144 hrs.	5	60	100	..	..	..	..	..	..	..	..	0	..
542	" worn 192 hrs.	5	60	80	80	80	80	100	..	..	..	..	0	..
546	" worn 216 hrs.	5	60	100	..	..	..	..	..	..	..	..	0	..
548	" worn 240 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
540	Tribrominated cresol liquid portion without paraffine worn 24 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
543	Tribrominated cresol liquid portion without paraffine worn 72 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
549	Tribrominated cresol liquid portion without paraffine worn 120 hrs.	5	60	100	..	..	..	..	..	..	..	..	0	..
554	Tribrominated cresol liquid portion without paraffine worn 168 hrs.	5	20	40	40	60	80	80	80	80	80	80	0	..
557	Tribrominated cresol liquid portion without paraffine worn 216 hrs.	5	0	0	80	80	80	80	80	80	80	80	0	..
556	Tribrominated tricresol crystals without paraffine worn 24 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
559	Tribrominated tricresol crystals without paraffine worn 48 hrs.	5	80	100	..	..	..	..	..	..	..	..	0	..
572	Tribrominated tricresol crystals without paraffine worn 120 hrs.	5	0	40	60	80	100	..	..	..	..	..	Immature	

TABLE XVI—*Continued*

IMPREGNATION WITH HALOGENATED CRESOLS

No.	Chemical	Total	Percentage dead in hours									Total eggs	Per cent hatched
			12	24	36	48	60	72	84	96	108	120		
544	Sodium salt of dibrominated tricresol 5 c.c. to 100 c.c. of sodium hydroxide 17.77 grams of solution taken up worn 48 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
550	Sodium salt of dibrominated tricresol 5 c.c. to 100 c.c. of sodium hydroxide 17.77 grams of solution taken up worn 96 hrs.	5	100	..	..	..	..	..	..	..	..	..	0	..
558	Sodium salt of dibrominated tricresol 5 c.c. to 100 c.c. of sodium hydroxide 17.77 grams of solution taken up worn 192 hrs.	5	80	100	..	..	..	..	..	..	..	..	0	..
571	Sodium salt of dibrominated tricresol 5 c.c. to 100 c.c. of sodium hydroxide 17.77 grams of solution taken up worn 264 hrs.	5	60	60	100	..	..	..	..	..	..	..	0	..
577	Sodium salt of dibrominated tricresol 5 c.c. to 100 c.c. of sodium hydroxide 17.77 grams of solution taken up worn 312 hrs.	5	40	80	100	..	..	..	..	..	..	..	0	..
581	Sodium salt of dibrominated tricresol 5 c.c. to 100 c.c. of sodium hydroxide 17.77 grams of solution taken up worn 336 hrs	5	40	100	..	..	..	..	..	..	..	..	0	..
582	Sodium salt of dibrominated tricresol 5 c.c. to 100 c.c. of sodium hydroxide 17.77 grams of solution taken up worn 360 hrs.	5	40	80	100	..	..	..	..	..	..	..	0	..
584	Sodium salt of dibrominated tricresol 5 c.c. to 100 c.c. of sodium hydroxide 17.77 grams of solution taken up worn 384 hrs.	5	0	20	60	100	..	..	..	..	..	..	0	..
547	Dibrominated naphthalene without paraffine worn 48 hrs..	5	20	20	80	80	100	..	..	..	..	..	0	..
570	Monobromnaphthalene without paraffine worn 48 hrs....	5	100	..	..	..	..	..	..	..	..	..	0	..
574	" " " worn 72 hrs....	5	100	..	..	..	..	..	..	..	..	..	0	..
578	" " " worn 96 hrs....	5	100	..	..	..	..	..	..	..	..	..	0	..
580	" " " worn 120 hrs....	5	40	40	100	..	..	..	..	..	..	..	0	..
583	" " " worn 144 hrs....	5	0	0	0	0	0	..	..	..	..	..	0	..

In these experiments, 1 gram of the chemical was used to impregnate 48 sq. inches of the cloth and 3 grams of paraffine m.p. 51° C. were added except where mentioned.

Upon the advice of Dean John R. Allen, of the College of Engineering of the University of Minnesota, the apparatus described below was constructed and proved satisfactory. (Figure 2.) A chimney of galvanized iron 2.8 meters long and 46 cm. in diameter was constructed, and an oblong door 35 cm. in length was cut in 96 cm. from one end. This door was closed with a latch and the apertures along its edges were sealed with a mixture of beeswax, paraffine, and vaseline to avoid the entrance of air. Across the central axis of the chimney just below this door were soldered three horizontal iron rods, and on these were laid a platform of stout wire mesh. It was upon this platform that the samples for evaporation were laid. A 12-inch electric fan was now placed within the chimney about 40 cm. from the end nearest the wire platform. It was placed exactly in the mid-axis of the chimney, facing away from the latter and at right angles to its long axis, so that when turned on, the stream of air was sucked, not driven, across the surfaces for evaporation. Tests made with tobacco smoke introduced at the further end of the chimney showed that the currents of air twist somewhat along the outer 2 inches of the chimney, but the currents down the greater part of the lumen were practically uniform and parallel to the long axis of the chimney. Uniform evaporation might, therefore, be expected from surfaces exposed anywhere, except at the extreme outer portions of the chimney's lumen. As will be seen, this expectation was well borne out by the experimental test.

It was found, however, that when squares of woolen cloth were used, the change in weight of the square, when cut from the same piece of goods, was far from being uniform, and that changes in the humidity of the air from hour to hour were followed by great and irregular changes in the weight of the squares. These variations were too large to permit the cresol evaporation from the cloth to be studied by simple weighing.

Accordingly, the substances were placed in the lid of small weighed Petri dishes, 7 cm. in diameter, enough substance being used just to cover the entire surface of the dish. In the case of crystalline compounds, these were first melted in a tube and then dropped upon the slightly heated dish, spread evenly while still in liquid form and then allowed to crystallize. In this way they also covered the entire surface of the dish, presenting the nearest approximation to a uniform surface (38.5 square centimeters) that was possible. In the case of the dibrommono-chlormetacresol, the melting point was so high that it was found more convenient first to dissolve the substance in ether and then to transfer the solution to the Petri dish and evaporate off the ether.

The dishes were then weighed and placed on the platform in the iron chimney, distributed symmetrically on both sides of the midline. The fan was then turned on and air sucked through the chimney for periods of half an hour, after which the dishes were weighed again and the loss of weight

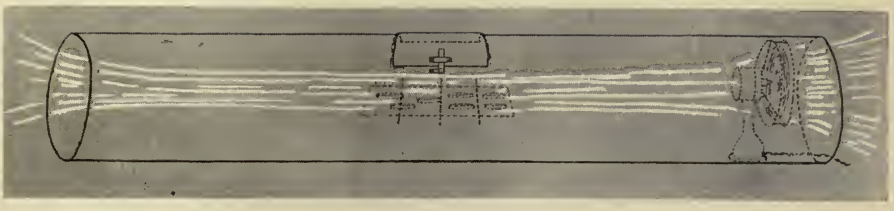


Figure 2

Sketch of apparatus used in the study of the volatility of different chemicals

determined. The loss of weight was quite as uniform as could be expected, the uniformity in the average changes being especially so. The rate of evaporation of the chemical shows a general conformity to the duration of its pediculicide action. (Table XVII.)

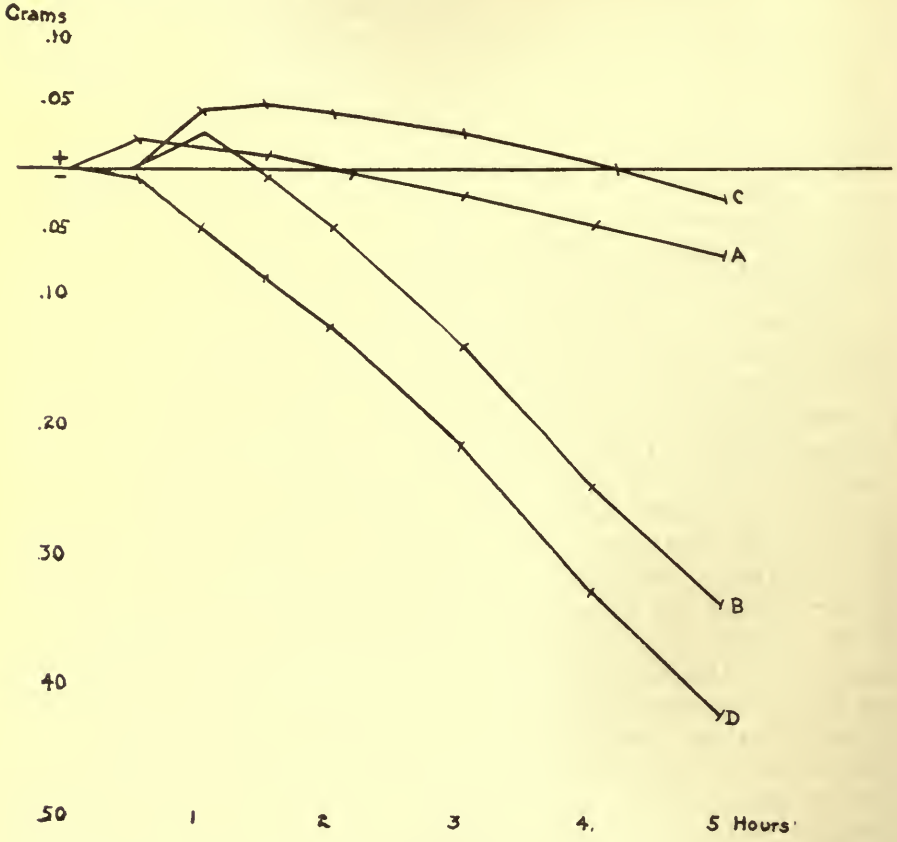
TABLE XVII

EVAPORATION PER HALF HOUR OF FANNING AT 72°–75° F. IN PETRI DISH 7 CM. IN DIAMETER (ABOUT 38.5 SQ. CM. SURFACE EXPOSED)

	Milligrams	Cresol coefficient. Mg. substance evaporating / Mg. cresol evaporating	Molecular cresol coefficient. Gram molecules substance / Gram molecules cresol
Metacresol	38.5	1.	1.
Monobrommetacresol	6.8	0.177	0.102
Dibrommetacresol	5.8	0.15	0.0609
Tribrommetacresol	0.3	0.008	0.0024
Dibrommonochlormetacresol	0.4	0.010	0.0036
Dichlormonobrommetacresol	0.5	0.013	0.0055
Crude cresol treated with 2 Br_2 liquid portion	0.9	0.0234	.....
Crude cresol treated with 2 Br_2 crystal portion	0.45	0.011	.....

Relationship to volatility, molecular weight, and toxicity to pediculicidal action.—Later experiments with the evaporation apparatus were carried out in a different laboratory, using a different fan, and were conducted at a different temperature; hence they can not be compared directly with those previously given. The Petri dishes used were uniform in size, giving a surface of 40.5 sq. cm. The temperature of the room was 25°–26° C. and the relative humidity varied between 50 to 65 per cent. The fan revolved at such a rate that a puff of tobacco smoke was carried the full length of the apparatus in 5 seconds, determined by a stop watch. A piece of sheet rubber packing was fastened on one side with adhesive tape and fitted under the door. By closing and clapping the door over this packing, all penetration of air along the edges of the door was prevented without the use of the mixture of beeswax, paraffine, and vaseline used previously. A glass plate was substituted for the wire netting, thus furnishing a more level surface for the Petri dishes. Loss of weight due to evaporation or gain in weight due to the absorption of water during weighing was prevented by weighing the dishes with their covers in place. The evaporation of compounds such as benzene was found to be retarded, due to the cooling effect produced by the rapid evaporation. By using a larger quantity of the chemical, 15 c.c. to 25 c.c., and running for periods of one half to one minute timed with a stop watch, this was overcome to a large extent. Less volatile chemicals were run for 15 to 30 minutes and in some cases for several hours between weighings. The first weighings usually did not represent the true loss by evaporation, since many of the chemicals first took up water, often so large an amount that an increase in weight resulted.

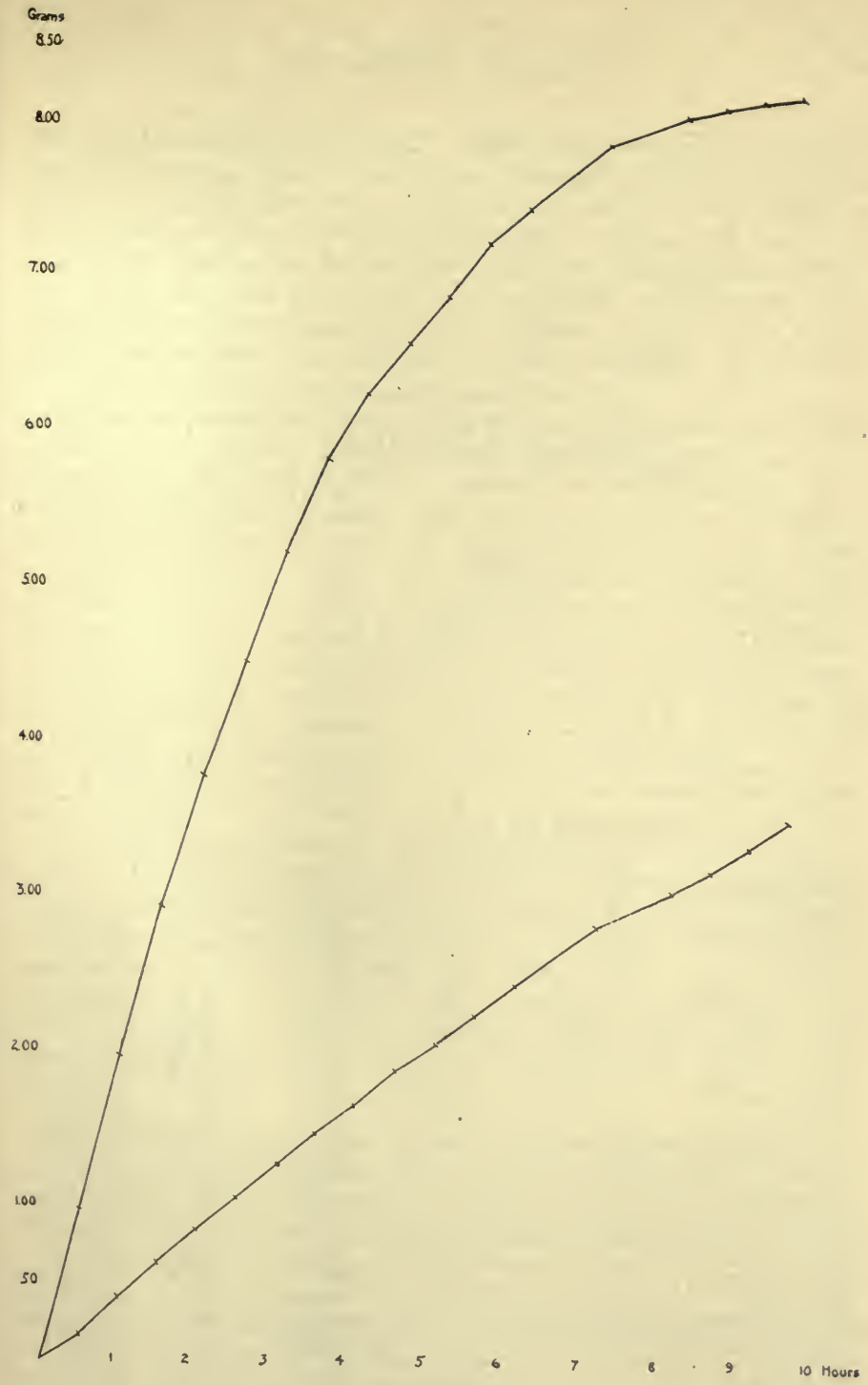
Curve 5 shows such an increase and also a comparison of the rate of absorption and rate of evaporation between dishes exposed inside and outside of the evaporation apparatus. The rate at which sulphuric acid will take up water in such an air current as compared with the still air is given in Curve 6. Impurities more volatile than the chemical to be tested were another source of error in the first weighings, hence only those weighings obtained after the loss had become uniform were accepted as representing the rate of evaporation of the chemical.



Curve 5

Showing gain and loss in weight of 2 grams (A and D) and 5 grams (B and C) of meta-cresol exposed in the evaporation apparatus (B and D) and outside the apparatus (A and C). Temperature 22°–24° C., relative humidity 55 per cent

Considering the possible substitutions in the benzene ring, the aldehydes are, as a rule, too unstable to give good results as pediculicides; while the amino and nitro groups are too toxic for the purpose. Only one hydroxyl group may be used since two hydroxyls reduce the volatility to such an extent as to make the chemical ineffective. Iodine is not abundant



Curve 6

Showing the increase in weight due to the absorption of water by 9. 2 grams of sulphuric acid exposed in the evaporating apparatus (upper curve) and outside apparatus (lower curve). Temperature 22°–24°C., relative humidity 55–60 per cent

enough to be used on so large a scale. There is left the methyl and similar groups, together with chlorine or bromine, as possible groups to be used to reduce the volatility. One hydroxyl group will furnish the desired toxicity to the chemical. Table XVIII gives the results of a study of possible compounds. When tribrommetacresol failed to kill it was thought to be due to its low volatility, but further study shows that even compounds much lower in volatility will kill quickly providing they have a high toxicity. Molecular weight or the size of the molecule appears to

TABLE XVIII

SHOWING IN GRAMS THE QUANTITY OF EACH CHEMICAL EVAPORATED FROM 1 SQ. IN. PER ½ HR. AT TEMPERATURE 76°–78° F.

Chemical	Grams per 1 sq. cm. per ½ hr.	Mol. weight	Time required to kill lice
Benzene	1.0339	.....	.....
Toluene	.2968	.....	.....
Xylene	.09815	.....	.....
Monobrombenzene	.08592	.....	.....
Monoiodobenzene	.0237	.....	.....
Benzaldehyde	.01214	.....	.....
Paradichlorbenzene	.010483	.....	.....
Benzyl alcohol	.0048086	.....	.....
Anilin	.00457	.....	.....
Mononitrobenzene	.003061	.....	.....
Orthocresol	.002987	.....	.....
Phenol	.002185	.....	.....
Paracresol methylether	.0016814	.....	.....
Orthocresol methylether	.0016148	.....	.....
Metacresol	.0013407	.....	.....
Tricresol–35 per cent ortho, 40 per cent meta, 25 per cent para	.0012479	.....	.....
Metacresol	.001180	.....	.....
Paradibrombenzene	.001120	.....	.....
Paracresol	.000881	.....	.....
Monobrommetacresol	.0008617	.....	within 12 hrs.
Naphthalene	.0008609	128.1	within 12 hrs.
Xylenol	.000824	122.	within 12 hrs.
Monochlororthocresol	.000800	142.46	within 12 hrs.
Monobromnaphthalene	.0007654	206.92	within 12 hrs.
Parachlorphenol	.000707	128.46	.....
Monobromxylenol	.000679	200.92	within 12 hrs.
Monoiodoorthocresol	.000572	233.92	within 12 hrs.
Dibrommetacresol	.000560	265.84	within 12 hrs.
Carvacrol	.00034	149	within 12 hrs.
Dibromtricresol	.000271	265.84	within 12 hrs.
Dibromxylenol	.000237	279.84	within 12 hrs.
Eugenol	.000171	164	within 12 hrs.
Tribromphenol	.0001673	330.76	within 60 hrs.
Monobromcarvacrol	.000142	227.92	within 12 hrs.
Tribrommetacresol	.0001	344.76	not killed
Heliotropine	.0000905	150.1	within 12 hrs.
Dibromnaphthalene	.0000781	285.84	within 60 hrs.
Dibromeugenol	.0000360	323.94	within 20 hrs.
Metadinitrobenzene	.0000074	168	within 12 hrs.
Alphanaphthol	.00000567	144	within 72 hrs.
Resorcinol*	.00000000	110	not killed
Paranitrophenol*	.0000000	139.01	not killed
Orcinol*	.0000000	110	not killed

* Probably oxidized since a slight increase in weight was noted.

have some bearing on the question. Whether the size of the molecule influences the penetration through the chitin, or whether the weight of the molecule influences the results by slowing down the rate of diffusion of the vapor, is not known. On the other hand, the bromine may act by reducing the toxicity of the chemical, since dibromeugenol, where the bromine is on the side chain, does not influence the toxicity as much as tribromphenol, tribrommetacresol, or dibromnaphthalene, where the bromine was introduced in the benzene ring.

Turning to the practical application of these data, it was found that the best of the less volatile compounds, dinitrobenzene, could not be used because of its high toxicity. Heliotropine tends to crystallize and is rubbed off the underwear by friction, while monobromcarvacrol disappeared from the underwear in ten days' time. Dibrommetacresol and the monobromdichlormetacresol was worn in warm weather under a B. V. D. suit of underwear and lasted 13 days, while monobromcarvacrol was worn in the cool autumn weather under a suit of gauze underwear. The rapid disappearance of the monobromcarvacrol can not be explained on the basis of volatility since it is only about one fifth as volatile as the dibrommetacresol; hence it must either be due to a more rapid absorption by the skin or to absorption in the surrounding clothing. If the latter view is correct, which appears probable, a field trial where the entire clothing would be treated should give better results with monobromcarvacrol than with dibrommetacresol. As far as our own tests upon pieces of cloth have actually demonstrated, however, the most lasting results have been obtained (in order of efficacy) with the sodium salt of the dibrominated crude cresol, the monobromdichlormetacresol, and the dibrommetacresol. A field study of these chemicals has not been possible, due to the signing of the armistice. All that can be stated concerning their value is that, under laboratory conditions, they give better results than are obtained in experiments with preparations already tested in the field; hence it is reasonable to hope that they would also prove superior under field conditions.

Summary

The entire investigation may be briefly summarized as follows:

1. Lice may be reared under incubator conditions in large numbers, if fed with human blood twice daily, but under such conditions the life cycle is slowed down, and the daily and total egg production per female is reduced.

2. Fever, rash, and a general lassitude are produced as a result of the louse bites.

3. Lice and their eggs are destroyed by the ordinary laundering processes used in the washing of cotton and khaki goods; for woolens slight alterations in the methods of washing are necessary.

4. Chlorpicrin may be used for fumigation of garments, accomplishing the desired results in a short period of time, with a small quantity of the chemical, without the use of high temperatures.

5. The sachet method of controlling lice is ineffective or very expensive.

6. Louse powders may be used with success but, being a wasteful method of applying an insecticide, are not recommended.

7. Impregnation of the underwear is the most promising method of louse control between lousings. Active chemicals of very low volatility are necessary to prove effective for the longest period of time. Halogenated phenols such as dibrommetacresol, dichlormonobrommetacresol, and their sodium salts, dibromcarvacrol, and dibromxylenol were found to be the most promising under laboratory conditions.

APPENDIX

APPENDIX

THE PREPARATION OF CERTAIN OF THE COMPOUNDS USED IN THE EXPERIMENTS

Since this research was undertaken with the purely utilitarian purpose of obtaining substances best suited for the killing of lice, this aim, rather than that of detailed chemical study, has remained paramount. Some of these substances such as dibrommetacresol, monobromdichlormetacresol, and dibrommonochlormetacresol are not described in Beilstein's *Handbuch der organischen Chemie*, Richter's *Lexikon der Kohlenstoff-Verbindungen*, nor Aberhalden's *Biochemisches Handlexikon*, nor in any of the articles of the literature consulted.

Brominated cresols.—Brominated cresols were prepared from stock samples (Kahlbaum) of orthometa and paracresol in two ways. First, the bromine was introduced into the benzene ring by the method which Koppeschaar described for the quantitative determination of cresol, using a mixture of sodium bromide 5/10 grm. mol. (=51.5 grm.) plus, sodium bromate 1/10 grm. mol. (=15.1 grm.) per liter. According to formula

$$5\,NaBr + NaBrO_3 + 6\,CH_3COOH = 3\,Br_2 + 6\,CH_3COONa + 3\,H_2O$$

1/10 grm. mol. of the cresol (10.8 grm. = 10.5 c.c. at 25°) or a proportionate amount, was first dissolved by adding sodium hydroxide solution, and the necessary amount of brominating solution, followed by sufficient glacial acetic acid to insure an excess, to bring about the desired one of the following reactions:

(1) $CH_3C_6H_4OH + Br_2 = CH_3C_6H_3BrOH + HBr$

(2) $CH_3C_6H_4OH + 2Br_2 = CH_3C_6H_2Br_2OH + 2HBr$

(3) For metacresol only

$CH_3C_6H_4OH + 3Br_2 = CH_3C_6HBr_3OH + 3HBr$

The mixture was always shaken in a mechanical shaker and allowed to stand from a few minutes to an hour until the reaction was complete. Completeness of the reaction was always tested by taking a small aliquot portion of the supernatant liquid as a sample adding 1-2 grm. KI, diluting with 20 c.c. H_2O and allowing to stand in the dark for 20 minutes, after which a little starch solution was added and the excess of iodine was titrated with n/10 sodium thiosulphate. Tho there was usually a trace of iodine liberated, the brominating reaction was usually practically complete within a few minutes.

The second method and the one which was used in making most of the bromine compounds was suggested by Professor W. H. Hunter of the School of Chemistry of the University of Minnesota. The cresol was dissolved in glacial acetic acid (200 to 500 c.c. per gram molecule used) in an Erlenmeyer flask, and a bit of fine bright iron wire was introduced as a catalyzer. The required amount of bromine (Br = 80, sp. gr. 2.99; $Br_2 = 160/3 = 53.3$ c.c.) was then measured out into a separatory funnel and allowed to drip slowly into the Erlenmeyer flask containing the cresol and acetic acid. Where relatively large amounts of bromine were used, the flask was placed in an iced bath. The reaction, as tested by the amount of iodine liberated on addition of KI to a sample, was found to be almost quantitative at the end of one hour.

The glacial acetic acid was then diluted with ten or twenty volumes of water, and shaken in a mechanical shaker for five minutes, after which it was allowed to stand for a few minutes, during which time the heavy brominated cresol settled to the bottom. The greater part of the supernatant liquid was then decanted off. When the brominated cresol was a solid, it was filtered off on a Buchner funnel; when a liquid, it was removed by means of a separatory funnel. In either case, the

excess of halogen was removed by shaking with an excess of 5 or 10 per cent sodium, thiosulphate, and allowing it to stand about an hour. This procedure removed not only the free bromine, but also liberated any bromine which might have replaced the hydrogen in the hydroxyl group of the cresol, for Ditz and Cedivoda have shown that when more than the equivalent of 2 Br_2 is added to ortho- or paracresol, or when more than 3 Br_2 is added to metacresol, such products are formed. When the proper amounts of bromine to exactly conform to the reactions (1), (2), and (3) above mentioned have been added, no appreciable amounts of these OBr compounds are formed.

After the substance was digested with sodium thiosulphate, the supernatant liquid was removed and the brominated cresol was shaken with dilute sodium bicarbonate solution until the supernatant liquid remained just alkaline to phenolsulphonphthalein. The chemical was then repeatedly washed by shaking with distilled water. The end product was finally separated from the water in a funnel or by filtration.

Chlorine was introduced into the benzene ring in the same general way, by dissolving the cresol in a counterpoised flask containing the cresol dissolved in glacial acetic acid cooled in an ice bath, and then passing in dry chlorine gas until the desired gain in weight was attained. As in the case of bromine, a bit of iron wire was used as the catalyzer. The chlorine was generated in the usual way by dropping concentrated hydrochloric acid from a separating funnel into a flask containing manganese dioxide. The flask was immersed in a boiling water bath. The chlorine was washed and dried by passage through water and concentrated sulphuric acid.

Excess of chlorine was tested for in the same manner as excess of bromine. The reaction, however, was complete, as in the case of bromine.

The dibrommonochlormetacresol was prepared from the dibrommetacresol by dissolving 28.6 grm. (1/10 grm. molecule) of the latter in glacial acetic acid, adding a little bright iron wire, and then placing the flask in an ice bath and passing in dry chlorine until the flask gained 7.1 grm. in weight ($=Cl_2$). After an hour's standing, a sample was tested with KI and thiosulphate and the reaction was found to be practically complete. The product was then prepared and purified in the same way as the other halogen derivatives.

The monobromdichlormetacresol was prepared from monobrommetacresol, by passing in 14.2 grm. ($=2\ Cl_2$) instead of 7.1 gram chlorine.

Iodine was found to enter the benzol ring of cresol somewhat less readily than chlorine or bromine. It was therefore introduced in an alkaline medium by the method described by Redman, Weith, and Brock, for the quantitative estimation of cresols. In one liter of normal (84 grm.) sodium bicarbonate 10.3 c.c. of cresol were dissolved and into this was poured (23.4 grm. = 1/10 gram molecules or multiples thereof) iodine which had been dissolved in 10 per cent KI solution. The mixture was shaken, acidified with acetic acid, digested, and finally washed in the manner described for the chlor and brom derivatives.

The iodo cresols were tarry masses with a sticky consistency and a very disagreeable odor, which facts considered with their lower killing power and much greater expense, render them less desirable for use as pediculicides.

After a considerable degree of success had been attained with the above mentioned halogenated metacresols, an attempt was made to brominate the crude cresols. When quantities equivalent to 2 Br_2 per molecule cresol were added to crude tricresol, the reaction proceeded quantitatively with the usual rapidity and a thick, syrupy liquid containing some small crystals was obtained. For purposes of brevity this was designated as "dibrominated tricresol," tho it was recognized that it was a mixture, and in all probability contained some monobromcresols and some tribrommetacresol. However, after the usual digestion with thiosulphate used in the process

of purification, there were certainly no -OBr compounds present in the substance when tested on the lice.

A similar preparation designated as "tribrominated tricresol" was also made using an equivalent of 3 Br_2 per molecule of tricresol. This contained a definite excess of Br_2 at the end of the hour, about equal to 1 Br. If, as is frequently the case, about 40 per cent of the tricresol is in the form of meta cresol, this would correspond very well to a yield of all the metacresol in the form of the tribrom compound and all the ortho and para in the form of dibrom substitution products.

In the course of bromination, a mass of beautiful needle-shaped crystals separated from the glacial acetic acid and was removed on a Buchner funnel. This, when purified, was designated as "tribrominated tricresol crystals" and the substance derived from the filtrate was, after purification, designated as "tribrominated tricresol liquid" altho, as a matter of fact, it probably represented chiefly dibrominated compounds (ortho- and paracresol). It crystallized into a homogeneous chocolate-like mass after standing several days.

Tested in the evaporation apparatus, the "crystal" fraction showed 0.45 mg. evaporation and the "liquid" fraction 0.9 mg. per half hour.

Separation of metacresol from ortho- and paracresol in crude cresol.—Since metacresol now on the market is quite expensive, it seems possible that this might be cheaply prepared for the purposes of this work by the method which has been described by P. Riehem. Riehem adds barium hydroxide solution to the crude cresol and concentrates the mixture. All the other salts crystallize before the barium metacresylate which remains in the mother liquor. This can then be freed from barium by the addition of mineral acids which causes the cresol to separate. The original ortho- and paracresol and all the barium used can, of course, be regained quantitatively.

Salts of cresols.—The compounds formed by cresols with various hydroxides were briefly studied. The sodium cresylates are sufficiently well known to require no further description. The sodium salts of dibrommetacresol and monobromdichlormetacresol were prepared by one of us by adding 3 per cent NaOH to an excess of the substance and allowing the mixture to stand upon which the excess settled out. This method seems at present to afford the greatest promise of all and warrants further investigation. The only drawback in practice seems to be the readiness with which sodium cresylate is soluble in water.

Upon standing or heating with calcium hydroxide, either solution or solid, calcium cresylates were readily formed. These calcium cresylates are somewhat less water-soluble than the sodium salts, and should therefore prove more useful.

The barium compounds are also readily prepared, but on account of the great toxicity of barium they could not be used in this work.

The aluminum cresylates have been described by Gladstone and Tribe. They are readily formed when the corresponding cresol is heated to its boiling point with aluminum under a reflux condenser in the presence of a small quantity of iodine. The reaction then proceeds with great violence, and in our experiments this was so great that several condensers and flasks were destroyed. By adding the cresol in relatively small fractions (not more than 50 c.c. at a time), however, no difficulty was encountered. The aluminum cresylates as described by Gladstone and Tribe are very unstable and break up at once upon contact with the air, to yield aluminum hydroxide and cresol.

Magnesium hydroxide readily forms a water-soluble cresylate with cresols, similar to the calcium cresylate.

Much might be hoped from a zinc compound, should it have properties somewhere midway between those of the magnesium and aluminum salts. Neither metal-

lic zinc nor zinc oxide, however, yielded a well-defined, soluble or insoluble zinc cresylate, nor was one readily obtained by the addition of zinc chloride to aqueous solution of sodium cresylate. It is possible that such a compound may be prepared by the action of zinc chloride upon dry sodium cresylate and if so, that its homologues made from sodium dibrommetacresylate or sodium monobromdichlormetacresylate might prove more useful than any of the substances studied.

Ferric hydroxide and ferric chloride in the presence of cresol dissolved in sodium hydroxide solution also failed to yield well-defined cresylates.

DESCRIPTION OF THE HALOGENATED CRESOLS

Monochlororthocresol.....light tan to orange colored; colored needle-like crystals
Monobromorthocresol.....brown liquid
Monochlormonobromorthocresol.....light orange, short and rather thick needle-like crystals
Dibromorthocresol.....white needle-like crystals, gradually turning to tan color on standing in closed flask. m.p. 66°–68°
Monoiodoorthocresol.....dark reddish brown liquid
Diiodoorthocresol.....
Monobrommetacresol.....light brown liquid, rather difficult to crystallize, even in freezing mixture. When crystalline, it forms white to orange needle-like crystals. Avr. evaporation per half hour ventilation 6.8 mg.
Dibrommetacresol.....white to light brown silky crystals. Average evaporation per half hour ventilation[62] 5.8 mg. m.p. 70°
Dibrommonochlormetacresol.....white needle-like crystals, gradually turning to light tan. Average evaporation per half hour 0.4 mg.
Monobromdichlormetacresol.....fine white needles; average evaporation per half hour 0.5 mg. m.p. 62°
Tribrommetacresol.....white to orange-yellow needles; average evaporation per half hour 0.3 mg.
Monobromparacresol.....light brown liquid

Preparation of other chemicals.—Among these may be mentioned cresyl benzoate, methylene dicresol, monocresyl phosphate and tricresyl phosphate, and a liquid distilled from aluminum cresylate at a temperature above 273°. This liquid had a pleasant odor resembling geraniums. It has been described by Gladstone and Tribe as containing both cresyl ether and cresyl ketone. In spite of its high boiling point and the fact that it at first killed lice, it soon lost this power, which originally may have been due not to the ether or the ketone, but to impurities remaining in the substance. It was not studied further.

A mixture of di and tetrachlor naphthalene was prepared by the method of Emil Fischer (mixing napthalene with powdered $KClO_3$ and dropping balls of the mixture into concentrated HCl). This also failed to give further promise, as did also the mono- and dibromnaphthalene prepared by the action of Br_2 and 2 Br_2 respectively upon naphthalene in glacial acetic acid. Neither of these compounds was nearly as satisfactory as the corresponding compounds of cresol, and the higher bromine compounds were therefore not prepared.

At an early stage of this work, dinaphthylmethane $CH_2\begin{matrix}/C_{10}H_7\\\backslash C_{10}H^7\end{matrix}$ was prepared by the method of Grabowski (by the action of 1 part methylal on 5 parts of naphthalene in chloroform to which 5.5 c.c. concentrated sulphuric acid was gradually added). This substance also was not suited for the louse-killing.

Attempts to produce pediculicide substances by the action of sulphur upon naphthalene and by the action of sulphur upon hexemethylene tetramine, as well as upon ammonia and formaldehyde in alkaline solution yielded nothing which gave any promise.

[62] 72°–75° F. Evaporation tested in apparatus described. Evaporation of metacresol per half hour = 38.5 mg.

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